JULY 2012

tunnels & tunnelling INTERNATIONAL

Middle East and Africa
A Moroccan microtunnelling record and a slew of hydropower projects

Amsterdam Metro
A special insight on the myriad problems faced by the project team

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Connaught breakout

Open excavation for the ancient tunnel

BREAKTHROUGH
SOLUTIONS FOR
TOUGH JOBS
AROUND THE WORLD

BEIJING METRO LINE 9 LOT 6
BEIJING, CHINA
RME246SE - Mixed Face 6.28 meter EPB TBM
Contractor: Beijing Urban Construction Group (BUCG)

- Completion of 2 parallel metro tunnels of 1.2 km each
- Lot 6: most challenging section in the 16.45 km Line 9 construction
- Tunnel drove under water table, river, lakes and a restricted zone
- Highly permeable gravel and cobble conglomerate geology
- High density of boulders encountered with average size >1m
- Equipped with unique heavy duty ripper teeth, 1200KW VFD main drive
- Successful completion demonstrates credibility and versatility of Caterpillar EPB technology in conquering complex geology

BUCG TBM project team celebrating with Caterpillar Tunneling representatives on the breakthrough of Lot 6 on April 10th, 2012 in the front of the "Diamond" TBM, as nicknamed by the contractor for its outstanding performance.

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contents

comment

Hammersmith hypocrites

Surely it is time the members of the public take responsibility for their actions. If you oppose a major construction project you should feel the consequences. And certainly if you oppose a project of national interest because of nimbyism you should be stripped of local interest developments.

This is at least applicable to one incident not far from T&T Towers. A major cause of congestion in the west London borough of Hammersmith is the Hammersmith flyover. This three-lane road has been beset by problems that have crippled local transportation. The residents of Hammersmith last month called for a tunnel to be built to alleviate the problems.

But *T&T* reported (see News In Depth, *T&TI* December 2011, page 10) that these 'Hammersmith hypocrites' aggressively objected to the proposed Thames Tunnel for the London Tideway projects. The tunnel is needed to prevent the flow of untreated sewage into the River Thames from the at-capacity Victoria sewer network. Combined sewer overflows are dumping waste into the Thames twice a week on average. Hammersmith and Fulham council took the view that as they will benefit least (being up steam of central London), but would need to house a large proportion of the works, they would object.

Now that the tables have turned and Hammersmith residents now need the city's support to relieve their congestion problems, perhaps they should be left to suffer.

The same could be said of the makers of the anti-Beverly Hills tunnel video. The tunnel, which is needed to encourage residents out of their cars and onto public transport was the subject of a fear mongering campaign as *T&T* reported last month. Perhaps the video authors should be tracked, their number plates taken and their cars clamped. If you rally all the project opponents it could be an effective form of congestion relief itself.

And surely there is not a reader out there that wouldn't like to see the aptly named 'Scat' lobby group (Seattle Citizens Against the Tunnel) be held accountable for the money wasted in battling their objections.

In practice there is an argument to be had as to how to deal with the beyond-nimbyism opponents to projects that have successfully stifled much needed works and in doing so have hindered their region's development.

We have in this space shown the very successful but controversial approach of cities such as Singapore that have no resident involvement in city planning and as a result are able to rapidly and efficiently develop major infrastructure projects (see comment, *T&TI* May 2011, page 3).

While public involvement is vital at some level, to what extent can you trade prosperity for democracy?

Ideas on a postcard.

Jon Young

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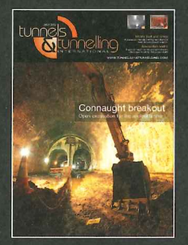

On the cover:
Difficulties on the Connaught tunnel refurb project in London, UK have seen a shift to open cut construction methods

ABU DHABI: SEWAGE SYSTEM WITH STRATEGY.

On the basis of the 2030 master plan, a gigantic new sewage network is being built in the desert metropolis of Abu Dhabi, which will connect new city and industrial areas. The "Strategic Tunnel Enhancement Program", in short "STEP", includes a main collector (deep tunnel sewer) with a length of 40 kilometers in three lots, as well as inflow link sewer and pump stations.

Herrenknecht has delivered five tunnel boring machines (EPB Shields ∅ 6,310 and 6,950mm) for the project lot 2 and 3 (T-02 and T-03). They are designed to withstand high groundwater pressures of up to 8bar, and have been working successfully since April 2011. In April and May 2012, Impregilo's tunnelling experts achieved breakthrough with the first 3 machines after daily top performances of up to 33 rings (Segment length: 1.400mm). The two other EPB Shields are underway at full speed. The concrete segments for the tunnel lining are delivered by a lining segment production plant installed near site, which was planned, equipped with moulds for lining segment production and put into operation with the help of Herrenknecht Formwork engineers.

The project is well underway with Herrenknecht technology and competent partners from the region. This means that Abu Dhabi will soon have plenty of purified water for the irrigation of the desert city.

ABU DHABI | UAE

PROJECT DATA	CONTRACTOR
S-582, S-583, S-584, S-649, S-654, 5x EPB Shields Diameter: 4x 6,310mm, 6,950mm Installed power: 3x 945kW, 2x 1,200kW Tunnel lengths: 4,885m, 2x 5,320m, 5,325m, 5,380m Geology: clay stone, gypsum, sandstone/limestone	Impregilo S.p.A.

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News in brief

Tunnel opens in the Netherlands after delay
After a two-year delay due to technical installation problems, on Monday 19 June construction workers opened the last of four tunnel tubes of the Leidsche Rijn road tunnel on the A2 highway near Utrecht, the capital city of the Netherlands.

Thailand tunnel to be completed by 2017
The Expressway Authority of Thailand (EXAT) governor, Aiyanat Tinapai, has announced that the Patong Tunnel project, which has an estimated cost of USD 188.7M, could be completed within five years. However, the proposed 165m tunnel still has to be approved by the Thai government.

USD 255M tunnel in Kentucky approved
The Federal Highway Administration approved construction of the USD 2.6bn Ohio River Bridges project, which includes a controversial USD 255M tunnel that Indiana will build in Kentucky. The tunnel will be dug underneath a property of disputed historic significance in Kentucky.

Lake Mead death under investigation

USA

The VTC worksite on the shores of Lake Mead with the segments in the foreground

State safety workers in Nevada are investigating a construction accident that killed one worker and injured another in the third intake at Lake Mead at around 4.30pm on Monday, 11 June. Thomas Albert Turner, 44, of Henderson, Nevada, was one of three crew members setting the 6ft-long (1.8m) ring of steel-reinforced concrete segments in the 20ft (6.1m) diameter tunnel. One of the segments slipped forward allowing pressurised grout to force through and strike Turner.

The segment did not fall down into the tunnel.

"There was a gap, and through that gap came the material, some grout and some rocks in sizes of 2in to 4in, (50-100mm)" said Robin Rockey spokesperson for the Southern Nevada Water Authority (SNWA). "It was about 200psi."

Initial reports from local media falsely announced workers had been trapped. "At no time were any workers trapped in the tunnel or exposed to toxic gasses. All other workers have been accounted for and are safe above ground. Furthermore, there was no flooding of the tunnel," said the SNWA in a release that day.

The accident happened 600ft underground at the worksite of Vegas Tunnel Constructors (VTC), a joint venture of Impregilo and its subsidiary S.A. Healy. VTC is building the 4.5km tunnel, which has seen several stops and starts due to flooding in the starter tunnel that eventually required realignment. On the evening of the incident VTC's Tunnel Rescue Team examined the site, and later determined the tunnel to be safe for entry. VTC is currently cleaning the space and preparing to seal the approximate 4in by 2ft (100mm by 610mm) gap where the tunnel ring segment slipped forward.

OSHA and VTC are conducting a joint investigation into the accident. Tunnelling activity will not resume until it is determined how the segment slipped and how to prevent future slippage. It is too early to determine how this could affect the project's schedule.

First Toronto Subway extension drive bored

CANADA

Some 1.6km of twin tunnels for the Toronto-York Spadina Subway Extension, part of the 8.6km northwestern extension subway line, has been completed. Progress was celebrated last month. The EPBM broke through the headwall at the Keele Street extraction shaft late May, representing the first major breakthrough for the project. The EPBM in the parallel drive broke through in early June, completing the second tunnel for this section.

Both machines are now being dismantled and moved to the second launch site. They will bore the next section of tunnel between Sheppard West Station and Downsview Station.

The estimated USD 2.6bn project is scheduled for completion in late 2015. Toronto Transit Commission is executing the project. It is expected to reduce commute times and ease traffic congestion for people living in the Greater Toronto area.

Bosphorus water supply tunnel completed

TURKEY

Turkish group STFA has announced completion of the construction of a water supply tunnel underneath the Bosphorus strait, which spans the Bosporus linking Asia to Europe. The tunnel will be operational next month.

At its deepest point, the tunnel runs 135m below the sea strait's water level.

Engineering the tunnel posed many technical challenges; the water is up to 70m deep, overlying a 70m thick layer of alluvium.

The tunnel is part of the USD 120M Melen Project. The tunnel will supply the European part of the city with about 3bn litres of water per day until 2040. Water is abstracted from the Melen River, stored in a holding reservoir and then fed through 170km of pipeline to the banks of the Bosphorus, where it is treated before passing through the 5.5km long tunnel.

It was excavated in a little over three years with the Herrenknecht S-391 TBM.

Thousands oppose New Zealand tunnel

NEW ZEALAND

An online petition opposing the longest bored tunnel in New Zealand, the Milford Passage, made international headlines earlier this month with the growing number of signatures it is receiving.

The petition has been the subject of national newspapers in Australia, Germany, Great Britain and The Netherlands. It now has more than 17,000 signatures.

The NZD 170m (USD 134m) proposal is to excavate the 11.6km tunnel by TBM. The Milford Dart company has been battling for more than five years to get the go-ahead for its plan to link Mount Aspiring and Fiordland National Parks under the Humboldt and Ailsa mountain ranges of New Zealand South Island's Southern Alps. The new route is intended for buses only and would cut journey times from Queenstown to the popular tourist destination of Milford Sound by three hours to just two hours. Milford Sound attracts more than 550,000 visitors per year, expected to rise to 750,000 this year.

Ohio's largest TBM ready to get digging

Left: The Herrenknecht TBM was ready to bore the Euclid Creek Storage tunnel as *T&TI* went to press

USA

Crews with the Northeast Ohio Regional District lowered the 27ft (8m) diameter Herrenknecht TBM in place to excavate the 5.5km Euclid Creek Storage Tunnel last month. It took several hours to position the machine down the 61m shaft to prepare it to begin boring.

Earlier this year, Tom Szaraz, project manager at McNally, told *T&TI*, "We are facing many time constraints. When the TBM is ready to launch in June we'll have approximately 15 months of mining ahead of us."

The TBM will launch on a very curvy alignment through chagrin shale bedrock and will vary between depths of 58 and 67m deep. The geology has a typical UCI of 69MPa. For a detailed report on the project see TTNA June-July, page 18.

The tunnel is the first in a series of storage tunnels being constructed as a part of Project Clean Lake, the Sewer District's 25 year, USD 3bn programme to cut the amount of combined sewage entering local waterways every year.

News in brief

San Pedro tunnel ready to enter service
The long-awaited San Pedro road tunnel is ready to open by the end of this month, confirmed the Spanish government in early June. The tunnel has been marred by controversy over non-payment of workers, loss of business and long delays.

European X-ray laser tunnels completed
After two years the European X-ray Free-Electron Laser International research facility has completed a 5.8km-long network of tunnels, which extend 3.4km from Hamburg-Bahrenfeld to Schenefeld in Schleswig-Holstein. By 2015, laser-like X-ray flashes that enable new insights into the nanoworld are expected to be generated in the tunnels by scientists across the globe.

BAM lands contract for Irish tunnel
Construction company BAM has been awarded the contract by Shell E&P for the construction of a 4.9km tunnel as part of the Corrib gas project. Tunnelling is planned to begin by the end of 2012 and is expected to take around 15 months.

Toronto backs tunnel toll

CANADA

Nine out of 10 people surveyed in Toronto and the surrounding region said traffic congestion has reached 'crisis proportions'. A majority support the construction of an underground toll road to relieve congestion on the Gardiner Expressway, according to the survey by Environics Research that was published by Toronto's The Globe and Mail. The study found that 52 per cent 'somewhat support' and 26 per cent 'strongly support' building a tunnelled highway from the Humber River to the Don Valley Parkway underneath the Gardiner.

The tunnels would be some 12km in length.

Darren Karasiuk, vice-president of corporate and public affairs at Environics told The Globe and Mail, "Transportation and transit issues are so very much at the forefront of people's minds that there's a willingness to look at all sorts of creative solutions."

Further 12 people add to Gaza tunnel casualties

GAZA

Palestinian medical sources in the Gaza Strip reported last month that 12 people were injured on Thursday 21 June after a supply tunnel collapsed, east of the Sheikh Zayed area in the northern part of the Gaza Strip.

Officials estimate at least 200 Palestinians have died in tunnel-related accidents, and more than 800 have been injured since Israel and Egypt imposed a siege on the Gaza Strip six years ago.

Since then, locals have made up for shortages through the use of goods and fuel smuggled from Egypt through a network of underground tunnels.

In March 2012, an 18-month-old Palestinian child was killed, and her three-year-old sister was seriously injured, after falling into a supply tunnel, in the city of Rafah, in the south of the Gaza Strip.

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San Francisco metro construction begins

USA

San Francisco's Municipal Transportation Agency (SFMTA) has started major construction to prepare for the Central Subway tunnel excavation.

While construction is in full swing, the agency is still waiting for the guaranteed federal funding that will allow it to start digging. Local and national newspapers report that the construction process means a summer of traffic detours, delays and also some parking restrictions.

On June 12, tunnelling contractor Barnard Impregilo Healy joint venture began excavating and constructing a launch box at the site where tunnelling will commence. Preliminary work on headwalls, 30m deep walls that will stretch across Fourth Street at the site of the Yerba Buena/Moscone Station began earlier this month.

"Crews will soon be building the first permanent components of the vital Central Subway extension of the T Third Line. This USD 233M contract will create jobs and contribute to the local economy," said Edward D Reiskin, director of transportation at SFMTA. "The launch box will become the portal where T Third Line trains will descend into the Central Subway tunnel, and the headwalls will be integrated into the two new subway stations.

"This work kicks off an exciting new phase for this essential upgrade of San Francisco's public transportation system."

Design contract awarded on planned rail tunnel for Gothenburg

SWEDEN

A consortium comprising Ramboll and transport consultancy Vectura has been awarded a major contract by the Swedish Transport Administration on the Vastlanken or West Link project in Gothenburg, Ramboll announced last month.

The project scope includes route planning for the line and connection points including within the tunnel. "West Link is one of the largest and most complex rail projects in Sweden today," said Borje Eriksson, division manager for Ramboll. "Working together with Ventura we can offer the customer the very best technical expertise in rail, tunnelling and ground engineering. We are extremely proud to have been appointed on such a prestigious and exciting project."

The contract is worth approximately EUR 11M (USD 13.8M). Work on the scheme will began as *T&TI* went to press and was expected to be completed by 2014. West Link comprises a train tunnel under central Gothenburg that will provide increased capacity, reduced travel times and improved access to the city centre. The geology in the city is mixed with the building in downtown Gothenburg built on marsh land with deep piles, while tunnelling on the outskirts of the city has been in hard rock.

Left: Gothenburg West Link Alignment map

Eastern Crossrail drive TBM assembly

GREAT BRITAIN

Assembly of Crossrail's next 1,000t TBM, Elizabeth, has commenced at Limmo Peninsula, a key worksite in east London, it was announced last month. Four of the eight Crossrail TBMs have been manufactured so far.

During the next four months, components for the 150m long Elizabeth will be transported to the Limmo worksite from Tilbury Docks and reassembled before being lowered in sections into two shafts. Once fully assembled below ground the TBM will begin constructing the first of Crossrail's two eastern running tunnels between Docklands and central London. Workers have reached the temporary bottom of the two launch shafts and have commenced work on sprayed concrete lined tunnels to connect the two shafts. The larger of the two shafts is 30m in diameter and will be 44m deep when completed.

Elizabeth and TBM Victoria will be launched from Limmo Peninsula. The machines will construct Crossrail's longest tunnel section running 8.3km to Farringdon station via Canary Wharf, Whitechapel and Liverpool Street. Victoria is due to commence tunnelling later this year. Crossrail will build a new dock and conveyer system at Limmo to take the excavated material from the eastern tunnels to Wallasea Island in Essex by ship. The excavated material will be used to create Europe's largest manmade inter-tidal nature reserve. The dock will also be used to receive more than 120,000 concrete segments that will line the tunnels. The concrete segments will be transported by ship to Limmo Peninsula from a pre-cast concrete segment factory at Chatham in Kent. Crossrail also announced last month that it had awarded the Tottenham Court Road station construction contract to UK contractor Laing O'Rourke.

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New Irvington Tunnel breakthrough

Left: The excavation began in May 2011 should complete in May/June

USA

Construction crews on San Francisco's 5.6km New Irvington tunnel, part of the city's Water System Improvement Program, achieved breakthrough the lead designer for the tunnel, Jacobs Associates announced last month. Miners excavating from the Irvington Portal in Fremont and the Vargas Shaft - at around 1,341m away - met underground after a 55t roadheader holed through and connected the two headings. The tunnel is a vital piece of the San Francisco Public Utilities Commission's USD 4.6bn improvement program to upgrade its entire aging Hetch Hetchy system. Following last month's hole-through, the tunnel miners will prepare this section of the tunnel for the installation of the 2,590mm steel liner.

The steel pipe will be installed in 15.2m sections and welded together inside of the tunnel.

The remaining section of tunnel, stretching from the Vargas Shaft east to the Alameda West Portal heading in Sunol, is much longer and is expected to break through in the third quarter of 2013.

TAC conference in Montreal

CANADA

Early registration offer for the Tunnel Association of Canada conference in Montreal closes this month. This three-day event will focus on tunnelling projects and advances in tunnelling technology, both in Canada and globally. Early registrants are entitled to a discounted rate.

The first two days of the conference will highlight the advancements and state-of-the-art status in tunnelling research and practice from around the globe. The third day will feature a technical tour of the Romaine-two hydro project. Participants will have the opportunity to visit the construction site of the largest hydroelectric development project presently underway in Quebec.

In-Mo Lee, president of the International Tunnelling Association will present on 'Underground Structures for Sustainable Development'; Felix Amberg, president of Amberg Engineering will tackle hard rock TBM tunnelling giving his account of the Gotthard experience; a leader in tunnelling research Daniele Peila of Politecnico di Torino will present on 'Soft Ground Soil Conditioning'; and Tarcisio Celestino of Universidade de Sao Paulo will inform on 'Soft Ground Tunnelling in an Urban Environment, Sao Paolo'.

The conference opens on 17 October at the Hyatt Regency Hotel, Montreal, Quebec, with the site visit on 20 October. For more information go to www.tac2012.ca

News in brief

Reconstruction of 103-year-old Delhi tunnel delayed
The plan to convert a century-old British era tunnel at the Old Delhi railway station into a subway for passengers might take a couple of years to complete. Construction work, which was meant to begin in February 2012 with a 10-month deadline, has not yet started. A senior railway officer said that water leakage and a shortage of funds have stalled the reconstruction.

Tunnel pioneer steps down
Tom Hanson, who helped spearhead the second Tyne Tunnel project that completed in November 2011, was thanked by political colleagues when he stepped down as a Labour councillor for the Bede ward, Jarrow, at the recent local elections.

Financing secured for Turkey tunnel project
SK Engineering & Construction announced that during July it will finalise the project-financing deals for building an undersea tunnel in Turkey. Following USD 280M from the Bank of Korea, funding worth USD 960M for the 5.4km tunnel under the Bosphorus Strait had been secured.

Beijing's 45km water tunnel

CHINA

Work on an underground water diversion tunnel to help bring water from the country's south to Beijing began last month. The tunnel involves an estimated investment of USD 1.4bn. Local water sources have been unable to meet the growing demand. The tunnel will supply water to the downtown area and two suburban areas in the southeast. Some 1bn cu.m of water will be diverted from the longest river in Asia, the Yangtze to Beijing annually through the middle route of the South-to-North Water Diversion Project.

The South-to-North Water Diversion Project is designed to divert water from the south of China to the country's arid northern regions. The scheme has already taken 50 years from conception to construction and is expected to take almost as long to construct. Planned for completion in 2050, it will eventually divert 44.8bn cu.m of water annually.

STEP's major breakthrough

UAE

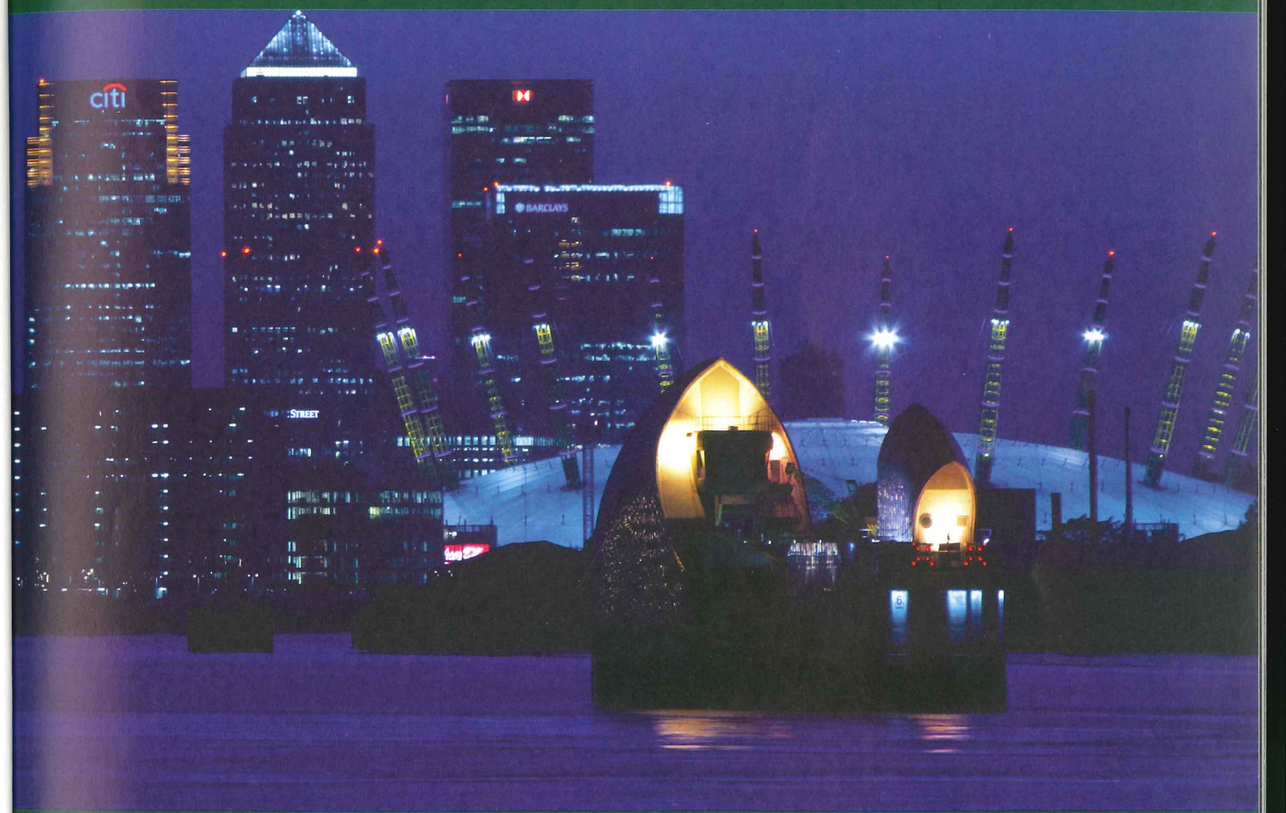
The Strategic Tunnel Enhancement Programme's (STEP) deep sewer tunnel in Abu Dhabi achieved major breakthrough with the third TBM late last month.

The third TBM completed excavation of the 4.9km length of tunnel running between shaft number seven and shaft number six near Al Mafraq in Mohammed Bin Zayed City, marking its accomplishment of contract T-02, a 15km central section of the sewer project.

The third TBM began tunnelling in July 2011 and progressed steadily at rates of up to 100m per week. The contract, worth AED 891M (USD 243M), was awarded to Impregilo on September 2009.

The total length of the STEP deep sewer tunnel is 41km. The third contract, also awarded to Impreglio, will complete the remainder of the tunnel drive. A total of eight TBMs will excavate the tunnel.

How do you drive a train under water?
Think Murphy.



First the Channel Tunnel Rail Link, now London's Crossrail. Tunnelling and underground construction specialist Murphy, is working below the River Thames again, in the £200 million project that will link East and West London. We are constructing The Thames Tunnel – two tunnels and portal structures totalling 8km in southeast London – connecting the district of Plumstead to North Woolwich and joining the existing North Kent rail line to Crossrail. Work has begun on this important and innovative transformation which is due to be completed by the end of 2015.

For more than 60 years, Murphy has been building and maintaining the infrastructure of the nation. We continue to break new ground with the design and construction of high profile projects across a range of key industries. From national tunnelling, power and rail projects to major water and wastewater contracts, pipelines, and process plant construction; with Murphy, the thinking is always as important as the delivery.

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Normet buys out TAM

FINLAND

Finnish technology company Normet has acquired the remaining 60 per cent of construction chemicals manufacturer TAM International, it was revealed last month.

"During the last two years of the partnership, TAM has grown significantly and now that it is fully integrated into Normet's own construction chemical business line, it makes us one of the leading specialist suppliers of process solutions to the global underground mining and tunnelling sector," said Tom Melbye, president of Normet Group and managing director of Normet International. "TAM's experienced and competent personnel and resources will only further strengthen Normet's ability to be a reliable, long-term partner for our customers in all different types of projects and conditions including underground, geotechnical engineering and general construction projects."

In April 2010 Normet acquired 40 per cent of TAM to form a global partnership. Going forward, all TAM companies worldwide will eventually operate under the Normet company name.

TAM will be retained as the product brand name for construction chemical products.

Strabag CEO and deputy CEO resign

Left: Thomas Birtel will take over as CEO of Strabag in June 2014

AUSTRIA

Hans Peter Haselsteiner will resign as CEO of Austrian contractor Strabag. Current board member Thomas Birtel will replace him following a board meeting in June 2014.

Deputy CEO Fritz Oberlerchner will also resign from the board effective 30 June 2012 to join a team tasked with evaluating Strabag strategies and organisation. He will not be replaced, reducing the size of Strabag's management board to five members.

Haselsteiner said, "I wish for Thomas Birtel to be my successor. For me, he is the natural choice: he is young enough to dynamically lead the group, old enough to avoid risk which cannot be controlled, and thanks to his position as management spokesman for Strabag Cologne, perfectly prepared to steer an even bigger ship.

"In our years of working together, he has always proven his professional and social competence.

"Our flexibility and our ability to quickly implement decisions form the basis for our success."

News in brief

Delhi Metro business development role for Sharma
Shri Sharma has taken charge as the new director, business development of the Delhi Metro Rail Corporation (DMRC). With his appointment, the number of full time directors in DMRC has increased to seven. Prior to his appointment, Sharma was working in DMRC as executive director, civil.

Balfour Beatty sponsors level one ADR programme
International infrastructure group Balfour Beatty last month announced that it will sponsor an American Depositary Receipt (ADR) programme to improve access for investors in the United States. ADRs allow US investors to buy shares in foreign companies without the need for cross-border or cross-currency transactions

Tunnel opens in The Netherlands after delay
Hong Kong based construction group Hip Hing won a total of five awards at the Considerate Contractor Site Award Scheme 2011. The scheme aims to promote a good attitude to health and safety and environmental concern and practices.

Poyry gets a new CEO

SWITZERLAND

The board of directors of engineering company Poyry has appointed Alexis Fries, 57, as the new president and CEO, the company announced yesterday. Fries will take up the position during autumn 2012 and will be based in Zurich.

Heikki Malinen left his position as president and CEO on 13 June 2012. The chairman of the board of directors, Henrik Ehrnrooth, will act as interim president and CEO until Fries takes over the position later this year. Malinen will support Ehrnrooth and Fries to ensure a smooth handover.

"I want to take this opportunity to thank Heikki Malinen for his dedication and commitment to Poyry during the past four years," said Ehrnrooth. "Despite the challenging business environment, Heikki Malinen has been driving the development of the company forward in many critical areas.

"I wish him all the best for his future career."

Eurotunnel's LSX change

GREAT BRITAIN

Groupe Eurotunnel is to become the first company to list on the London-based market operated by NYSE Euronext, the transatlantic exchanges operator, it was announced today. The operator of the channel tunnel will switch its listing from the London Stock Exchange next month.

"This is a significant and exciting new chapter for the two companies and we are delighted to welcome Groupe Eurotunnel as the first company to be admitted to trading on NYSE Euronext's London trading venue," said Dominique Cerutti, president and deputy chief executive officer, NYSE Euronext. "We believe that we are offering a superior alternative to companies wishing to list here thanks to the strength and visibility of our global brand."

Jacques Gounon, chairman and CEO of Groupe Eurotunnel added: "Today's move will allow investors to have easier access to Groupe Eurotunnel shares."

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Driver suspect in Swiss coach crash

A preliminary report into the Sierre Tunnel coach crash in Switzerland in March that left 28 people dead indicates that the driver was the cause.

The report, presented by the public prosecutor of Canton Valais where the accident occurred, ruled out the involvement of a third party, shortcomings in the road surface or the tunnel infrastructure, excessive speed, alcohol or technical problems with the coach.

Investigations are now concentrating on the driver. It is hoped to have the results of toxicology tests on the driver before the end of summer although it is already known that he had not drunk any alcohol. Belgian Transport Minister Melchior Wathelet said shortly after the crash that both drivers were well rested.

They were hired to conduct tourists away from a ski resort and had arrived the night before, resting during the day before departure as per the law. There was no indication of illness.

Swiss journalist Ruth Seeholzer told UK national media company *the BBC* that driving conditions were normal and the two-lane tunnel was not busy with traffic when the accident happened.

The 34-year-old had taken over the wheel from his colleague shortly before the head-on crash occurred. The twin-bore 2.6km Sierre tunnel, which features two lanes in each direction and emergency lay-bys at 600m intervals, has a maximum speed permitted of 100km per hour. The coach was travelling at between 99 and 101km per hour.

The coach touched the right kerb about 75m before the site of the collision, travelled along it and crashed into a wall in less than three seconds. There were no significant indications that the driver had tried to change direction or brake.

Peter Bishop, chairman of the Road Tunnel Operator Association told *T&TI* in March, "I've examined the photos carefully. The crash definitely occurred in a lay-by. It was not clear at first as it looked like a built-out structure. The tunnel is 2.6km-long with twin tubes very close together.

"The European Tunnel Register requires tunnels of this length to have lay-bys and safety niches. It seems that the driver lost control of the vehicle and mounted the kerb before hitting the wall."

Although UK paper *The Telegraph* reported that the Swiss Federal Office for Roads was examining whether the angle of the wall increased the severity of the crash, Bishop added, "The problem with permanently changing the angle of the wall, or introducing crash barriers is the deflection factor. The vehicle will deflect. This can be into the traffic of the tunnel and you can have a far worse accident involving many vehicles. It also comes to likelihood, the aperture of this lay-by measured against the entire length of the tunnel is very small. Crash cushions have been proposed in the past, but the angle of impact required is awkward in a tunnel."

A police spokesman said in March that reports that the driver was changing a DVD at the time of the crash were "pure speculation". Swiss newspaper *Le Matin Dimanch* quoted the father of an injured victim saying the last thing his daughter remembered was a teacher approaching the driver with a DVD. Bishop concluded, "Speed is the vital factor in tunnel crashes. It would have made an awful difference in this case as the smallest error of judgement is needed for a disaster. I don't think a catastrophe of this magnitude could have been prevented, but we are pushing for speed reductions with the UK Highways Agency. All tunnel designers will now be looking at their structures," Bishop added.

Rhian Owen & Alex Conacher

Right: The wall that the coach struck has since had safety barriers erected, despite the danger of deflecting collisions back into the traffic flow

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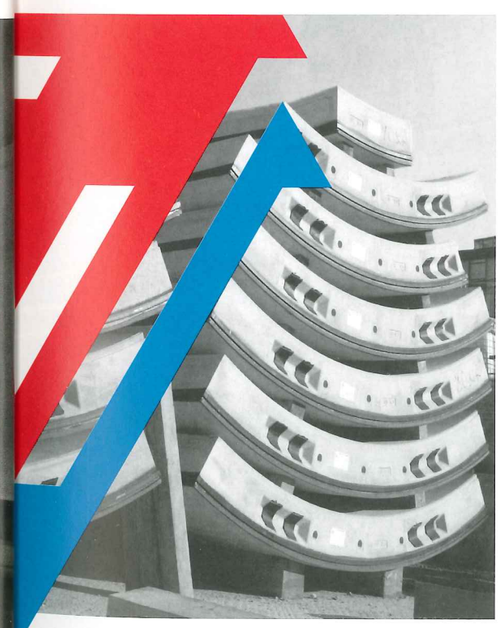
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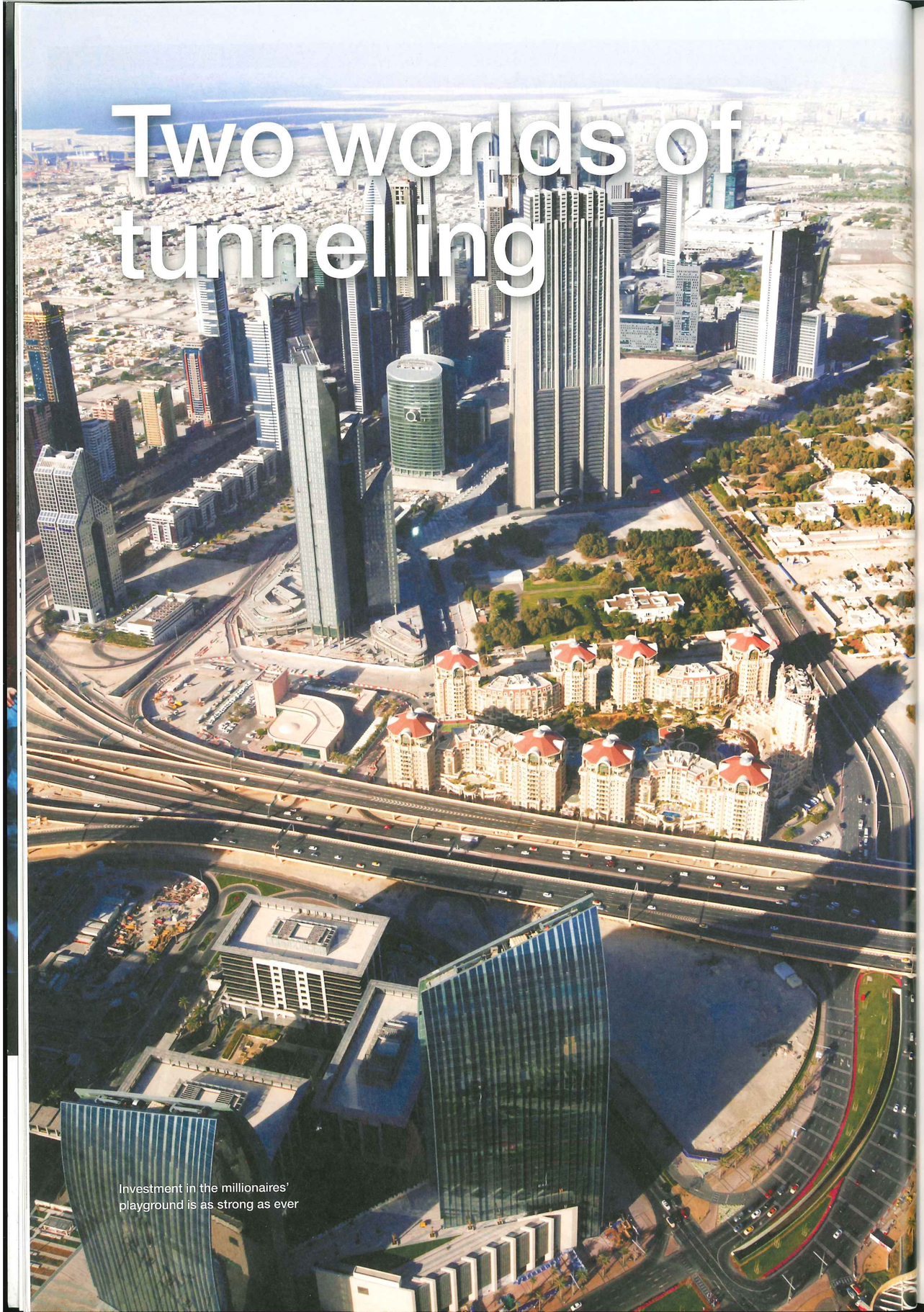


Investment in the millionaires' playground is as strong as ever

The Middle East stays strong on tunnelling for its new dream cities, while a belt of hydropower projects buoys the African market. Alex Conacher reports

The Middle East and Africa region is split between two worlds. On the one hand, wealthy kingdoms plan new cities with the associated transportation, water conveyance, sewage, and air-conditioned beaches. On the other, ancient cities predating western civilisation are heaved up to code as the existing, aged, infrastructure strains under a booming population.

UAE steps up

According to economic research entity timetric, by 2030 the population of the UAE is expected to have grown by between three and five million.

To cater to this rapidly growing population the UAE government had earmarked AED 55.1bn (USD 15bn) for the expansion of infrastructure projects between 2009 and 2012 in order to meet the demand for increased water, power and sewage facilities across the emirates.

Abu Dhabi's USD 1.6bn Strategic Tunnel Enhancement Project (STEP) is one of the investments. A 41km deep sewer tunnel, connecting pipework and a huge pumping station will lift wastewater flows to the new Al Wathba treatment works. The project was split into three main contract packages: T01, T02 and T03 that include a combined eight bores of around 5km.

As *T&TI* goes to press, the third TBM on Deep Tunnel Contract T02 has broken through, completing the 15km of tunnel for the package. The machine, launched in July 2011 executed a 4.9km drive between shafts seven and six in the Mohammed Bin Zayed City in Abu Dhabi.

A special insight on the Abu Dhabi Sewerage Services Company's project was published in *T&TI* February 2012, page 35.

Countries such as the UAE, whose economies are based upon financial services, air transport, property development and tourism require an efficient public transport network to function effectively and cope with an influx of tourists, business professionals and economic migrants.

In order to rectify the traffic congestion problems caused by Dubai's rapidly growing population the UAE government laid out a map for a metro rail network in February 2006, centered on the 52.1km Red Line.

A third of the Red Line's stations opened in September 2009, making Dubai the first urban metro network in the Gulf's Arab states, with further openings staggered into 2010. In addition, a Green Line has been completed and a further three lines are planned. The UAE government has set a target of putting 320km of metro lines in place in Dubai by 2020.

Above: **TBM lowering on Abu Dhabi's STEP project**

Below: **TBM launch on an Algiers sewer microtunnel by Denys**

Moroccan pipe jack

The Moroccan government is investing more than MAD 127.4bn (USD 15bn) by 2015 in order to upgrade the country's basic infrastructure. The sector has benefited from this, recording a compound annual growth rate of 6.67 per cent in 2010.

One of the tunnelling projects to upgrade Casablanca's sewer works is a 2.5km-long, 2.5m-diameter microtunnelling operation to connect the sewers to the new Sidi Bernoussi water treatment plant.

The sandstone geology is fairly homogenous in the area, though abrasive. Belgium conractor Denys and local Moroccan construction company Capep are executing the drive with a Herrenknecht AVN2500 machine (see feature, page 18).

Ingula Pumped Storage Scheme

The 1,332MW dual-reservoir scheme will go some way to solving a looming South African energy crisis. The *T&TI* projects map for the region on page 16 shows Ingula is part of a belt of hydropower projects running from Uganda down the east coast of the continent. The 2.1km-long twin headrace tunnels and a 2.3km long tailrace tunnel are driven through heavily jointed dolerite (see feature, page 21).

Riyadh development

Saudi Arabia's capital Riyadh is the target for a new USD 3bn metro system. The deadline for companies to register their interest was 20 June and the 40km project should be complete within four years.

The King Abdullah and Riyadh Airport tunnel projects show the geology and construction attitudes of the area well. The open cut can be made vertically without shoring. It is highly stable rock but with many cavities which increases the cost for contractor Almabani.

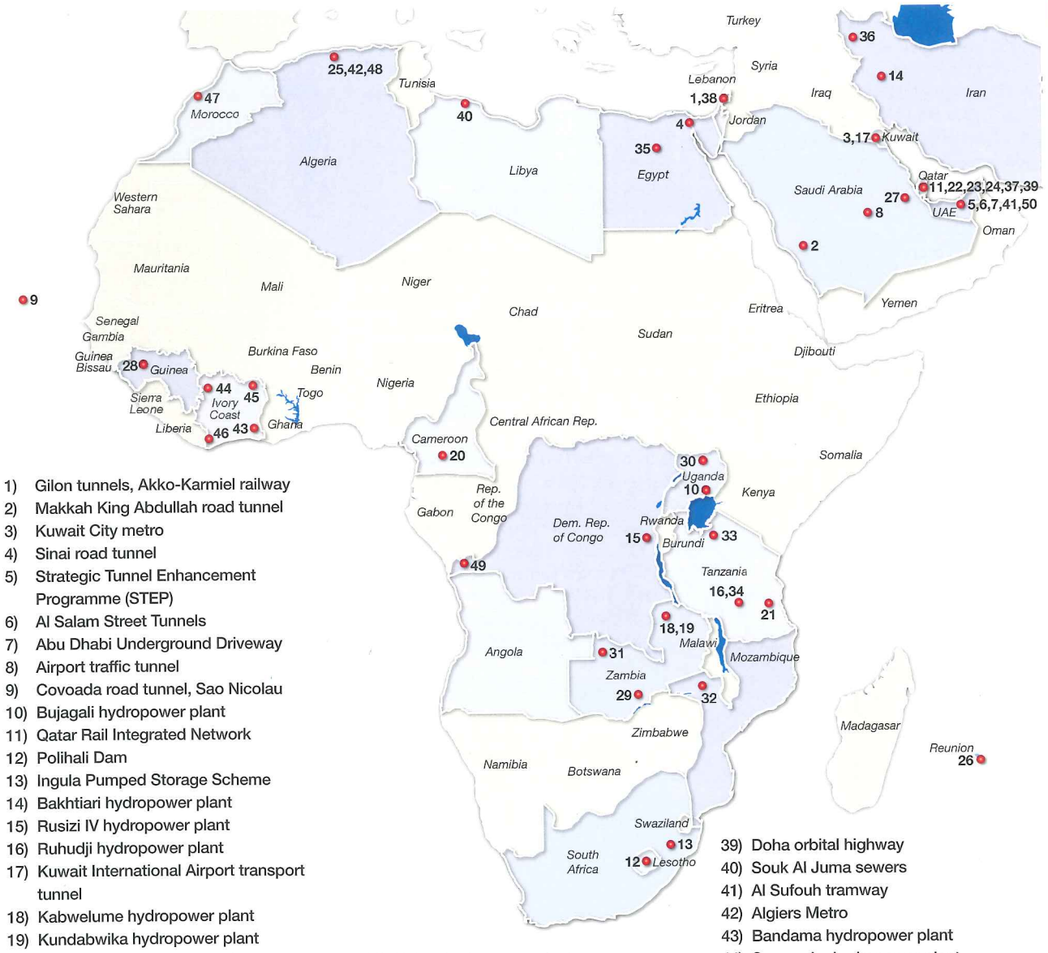
The tunnels go beneath existing runways and taxiways that were interrupted and then rebuilt afterwards. The Arriyadh Development authority is the client for these and the new metro system. Consultancy for the Riyadh airport tunnel and King Abdullah road tunnel was by Bernard of Austria.

Acknowledgement

Additional material by timetric.com

Advancing Africa

The extent of tunnelling in the Middle East is well known. And while Africa is hardly synonymous with massive investment programmes, the amount of tunnelling is significan. Alex Conacher takes a look



1) Gilon tunnels, Akko-Karmiel railway
2) Makkah King Abdullah road tunnel
3) Kuwait City metro
4) Sinai road tunnel
5) Strategic Tunnel Enhancement Programme (STEP)
6) Al Salam Street Tunnels
7) Abu Dhabi Underground Driveway
8) Airport traffic tunnel
9) Covoada road tunnel, Sao Nicolau
10) Bujagali hydropower plant
11) Qatar Rail Integrated Network
12) Polihali Dam
13) Ingula Pumped Storage Scheme
14) Bakhtiari hydropower plant
15) Rusizi IV hydropower plant
16) Ruhudji hydropower plant
17) Kuwait International Airport transport tunnel
18) Kabwelume hydropower plant
19) Kundabwika hydropower plant
20) Lom Pangar hydropower plant
21) Stiegler's Gorge hydropower plant
22) Doha north sewage treatment plant
23) Doha south sewage treatment plant
24) Inner Doha Resewerage Integrated System study
25) Annaba-Ramdane Djamel rail tunnels
26) Route du Littoral Coastal Driveway, Reunion Island
27) Al Uruba and Abu Bakr Siddiq road extensions
28) Kaleta hydropower plant
29) Kariba north bank hydropower plant
30) Karuma hydropower plant
31) Kabompo Gorge hydropower plant
32) Mphanda Nkuwa hydropower plant
33) Rusumo Falls hydropower plant
34) Rumakali hydropower plant
35) Cairo Metro
36) Aras hydropower plants
37) Al Khor-Al Ruwais road project
38) South Raanana rail interchange
39) Doha orbital highway
40) Souk Al Juma sewers
41) Al Sufouh tramway
42) Algiers Metro
43) Bandama hydropower plant
44) Sassandra hydropower plant
45) Comoe hydropower plant
46) Cavally hydropower plant
47) Sidi Bernoussi water treatment plant connection
48) Algiers sewer connection
49) Grand Inga hydropower plant
50) Ruwais gas storage tanks

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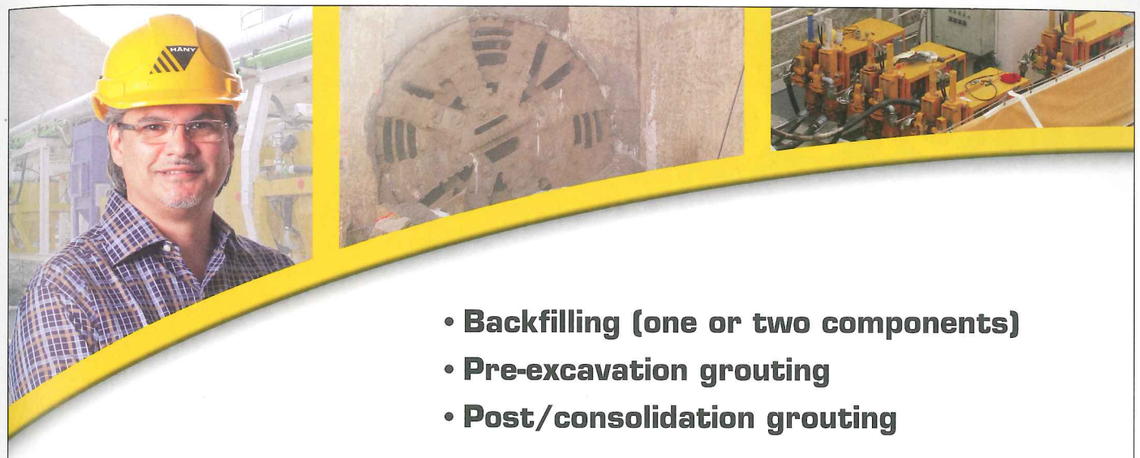

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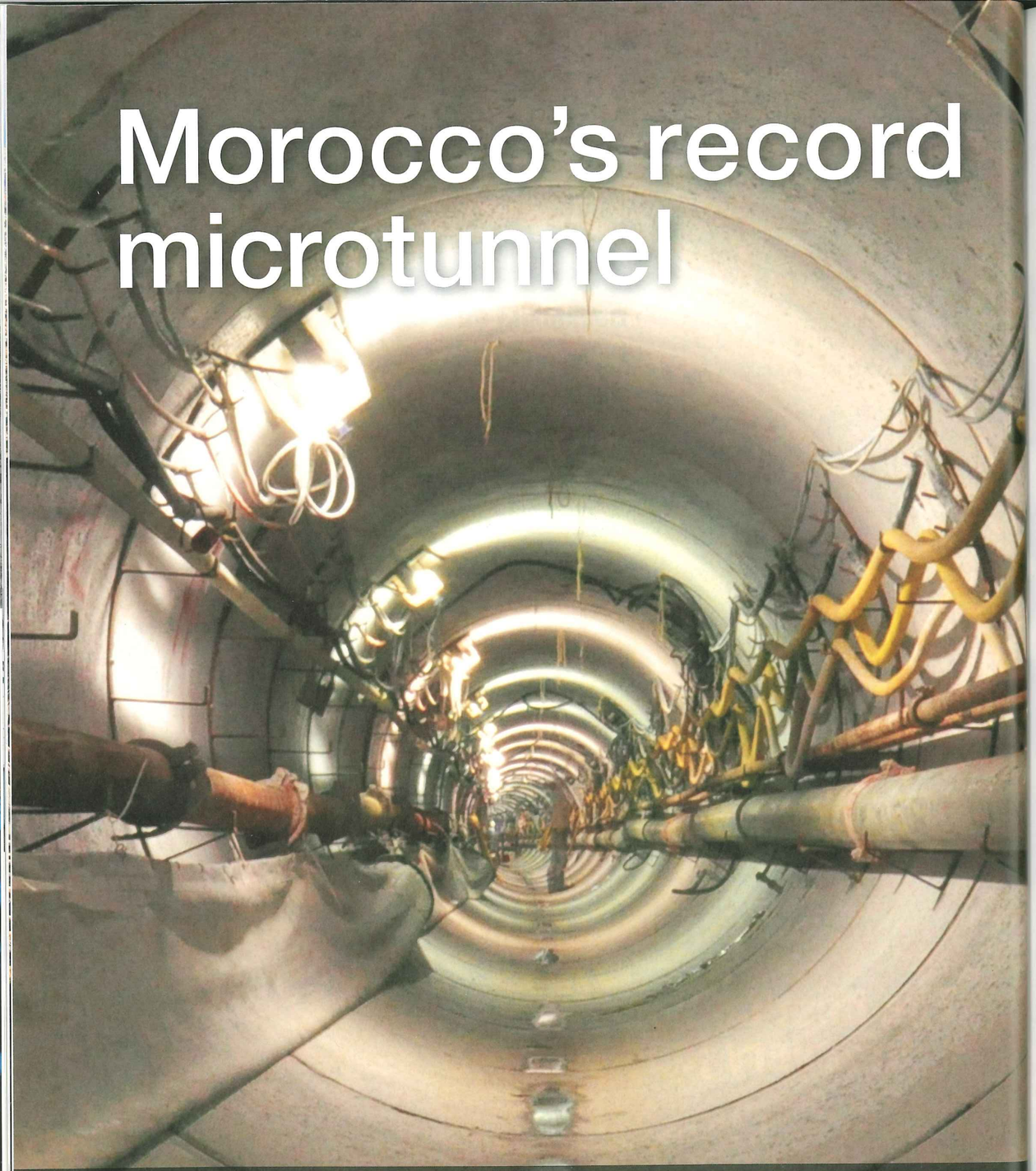
Morocco's record microtunnel



Morocco's biggest microtunnelling project in length and diameter is Casablanca's first as the city prepares to connect a new water treatment plant to its sewer network. Dirk Derycke, division manager tunnelling for Belgian contractor Denys gives this report on works in progress

The drives will be completed by the end of 2012

On 23 May 2011 the construction contract for the biggest microtunnelling project in Morocco, a new connecting sewer in Casablanca, was awarded to the joint venture of Denys and Capep. The sewer will link a future water treatment plant, Sidi Bernoussi, to the sewer network. The plant, to be built in east Casablanca, will treat sewage that is currently just flowing into the Atlantic Ocean.

The project called for the construction of a tunnel with internal diameter 2.5m by microtunnelling over a total length of 2,570m. It runs parallel to the ocean, to the east of Casablanca's harbour arm.

The underground option was chosen by water firm Lyonnaise Des Eaux de Casablanca (Lydec) and consultant Safege-C3E due to the highly water-permeable sandstone, the depth of the sewer under the groundwater table and the need to minimise the perturbation of the important economic activity on the surface.

Shafts and connectors

Next to the main sewer, two big connections have to be constructed as an overflow to the Atlantic Ocean. Also two launch shafts, two reception shafts and four intermediate shafts at 10 to 18m deep.

To realise the shafts, a lot of utilities had to be located and removed in this densely occupied urban area, thick with important harbour-related activities. For the first five to 8m the shafts were sunk by a system of vertical beams drilled in the ground, and horizontal sheets because of the presence of sand, clay and stones.

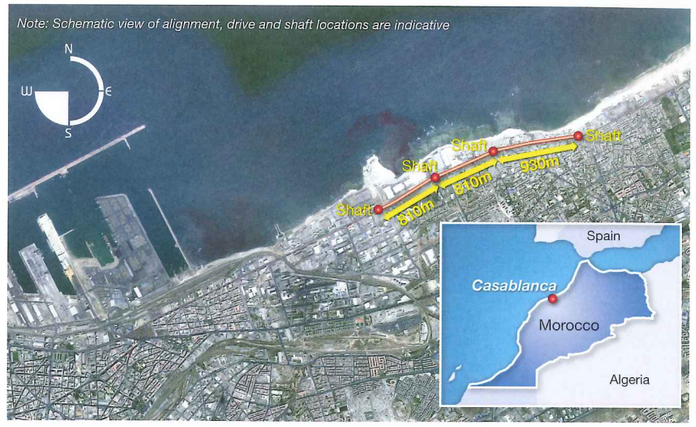
Afterwards excavation continued through the fractured and permeable siltstone. Iron nets were fixed against the side walls to prevent stones falling down, and a plastic membrane led the infiltrated water to the bottom of the shaft where it flows into a central pumping pit.

Rock-anchors were necessary in a lot of places to consolidate the rock.

The first shaft was ready approximately five months after the starting-date of the project. At the beginning of December the first of the tunnelling equipment arrived on the jobsite after a long and difficult journey and the associated customs-related problems that had to be resolved.

Excavation and progress

Denys commissioned a microtunnelling machine from Herrenknecht. It is an AVN2500 equipped with a rock cutting head, a slurry-evacuation system and an integrated air-lock-system to enable cutting tool changes under compressed air.



Vital statistics

Contractor: Joint venture of Denys and local contractor Capep

Consultant: Safege-C3E

Client: Lydec

Length: Three curved drives of 930m, 810m and 810m.

Diameter: All drives 2.5m internal diameter, 3m external

Shafts: Four launch and reception shafts and then four intermediate shafts to be constructed after the drives

Equipment: Herrenknecht AVN2500 slurry machine with rock cutting head

Excavation schedule: January 2012 to December 2012

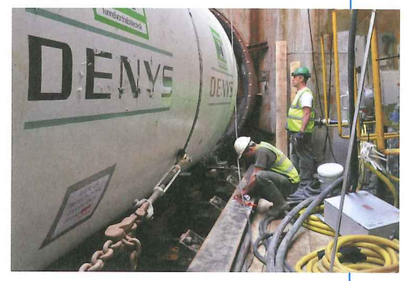
Geology: Homogenous sandstone up to 100MPa with water inflows

Before the tender, probes were taken after vertical drilling to perform UCS, Lugeon and rock-quality designation (RQD) tests. These found 30 to 80MPa UCI rock. The geology that had to be crossed has been rather homogeneous, very permeable and fractured siltstone and sandstone. Compressive strengths range from 30 to 120MPa UCI. Water infiltration was manageable without injections.

The machine was lowered into the shaft in the middle of January, starting the first drive shortly after.

The total drive length of 2,570m is split into three separate drives with a length of 930m, 810m and 810m. The first drive of 930m, realised in a two-shift pattern, broke through on 16 May.

The drives are designed with a low vertical slope of approximately 1mm/m and



Above: Launch of the machine

with different horizontal curves with radii of 900 to 1,100m. The curves were to enable the location of launch and reception shafts at places where the surface impact would be minimal.

A different cutter-disc changing schedule had to be programmed during the first drive due to the abrasivity of the sandstone. At each intervention the full set of 18 of the 300mm-cutting-discs had to be replaced by new ones.

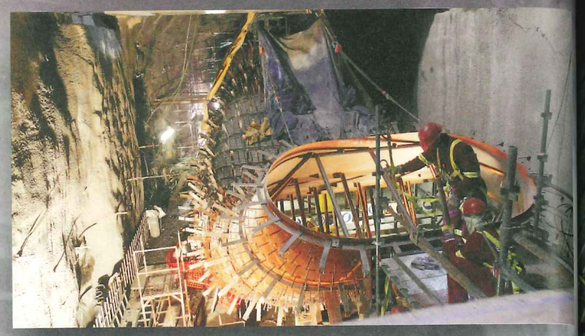
Guidance

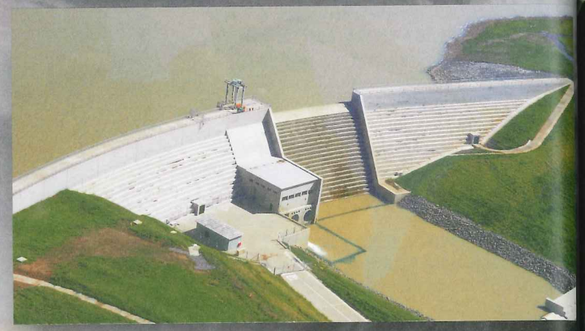
Denys uses one of its SLS-RV-guidance-systems, bought from VMT. During the first drive, deviations after each control measurement in horizontal and vertical planes were minimal.

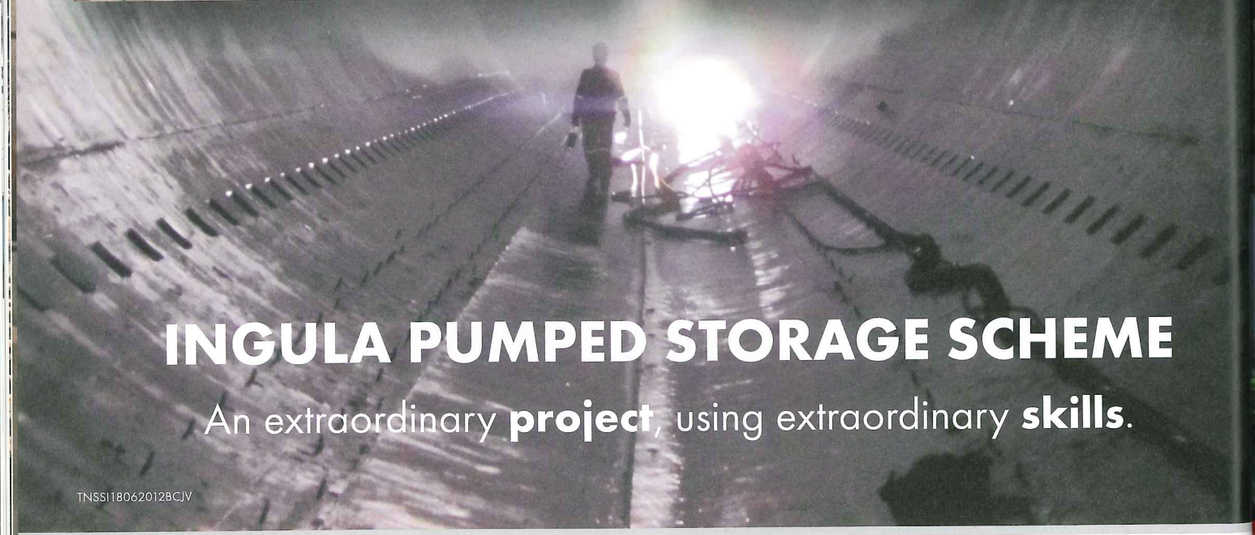
We are scheduled to finish both remaining drives by the end of 2012.

The contractors

Capep is a leading Moroccan construction company active in concrete construction, excavation and water work. Denys is based in Belgium and works in gas, water, renovation and construction in Europe, Africa and the Middle East.







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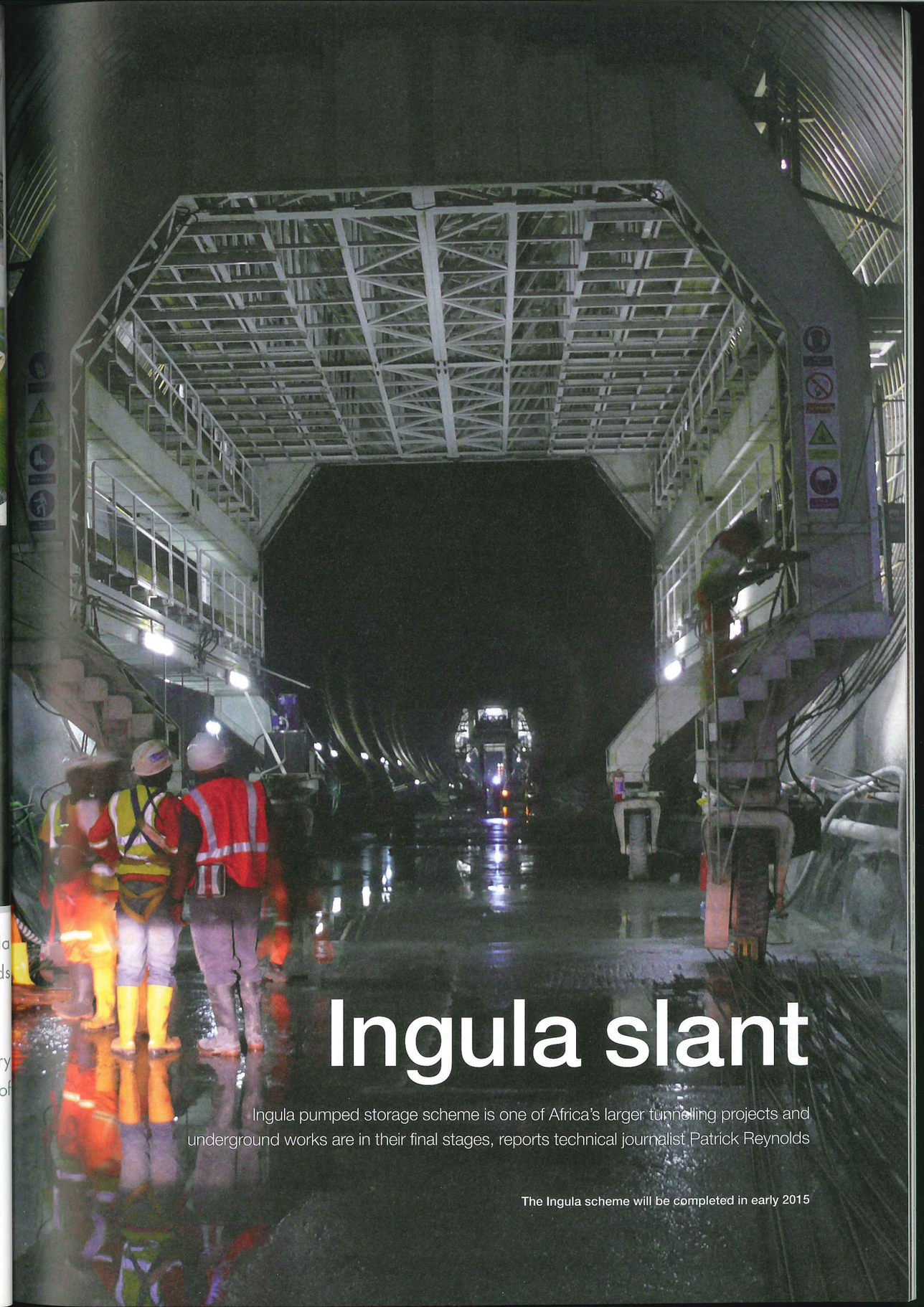


Ingula slant

Ingula pumped storage scheme is one of Africa's larger tunnelling projects and underground works are in their final stages, reports technical journalist Patrick Reynolds

The Ingula scheme will be completed in early 2015

The main challenges of tunnel excavation have passed at Ingula pumped storage project in South Africa. The underground construction effort has switched to final lining. Concreting works are also underway for the powerhouse cavern foundations to hold four massive pump-turbine units.

"Tunnel and cavern excavation is virtually complete, with some excavations still ongoing," says John Sawyer, project engineering manager for the developer, South African energy utility Eskom. "Concrete and steel lining of the headrace and tailrace tunnels has now started, but is at an early stage."

The 1,332MW scheme will use two reservoirs. While the dams for both are complete, and the lower one – Bramhoek – is already full, the upper pond intake works at the top of the headrace still need to be completed before filling can be finished.

But the main challenge was the geology for the underground works. The geology comprises relatively weak sedimentary rock with some faults and fractures in the complex powerhouse area, long-term creep behaviour and the relatively low insitu stress at depth for the twin power tunnels.

Sawyer says the current schedule is for the generation units in the powerhouse, almost 400m below ground, to be commissioned at intervals throughout 2014. The Ingula scheme is to be completed in early 2015.

Contractor for the underground works on the scheme is a JV of Italian firms CMC and Impregilo with local company Mavundla. The design JV comprises Arcus Gibb, SSI (part of DHV), and Knight Piesold, operating as Braamhoek Consultant JV.

Project features

The Ingula pumped storage scheme has been designed to work under a rated head of 441m between two reservoirs, the upper Bedford and lower Bramhoek, both new impounded water bodes and positioned approximately 6km apart. The hydraulic system will hold 21GWh, or almost 16 hours of energy generation, although it would take about 20 hours of pumping to charge the system.

Driving the flows back-and-forth in the scheme, typically over a weekly cycle, will be the powerhouse which is being constructed underground, below under a prominent mountain ridge that features complex local geology between the reservoirs. The powerhouse will hold four large (333MW) Francis pump-turbines.

Despite the large reservoirs and dam construction on the scheme, the project

Right: The Ingula Pumped Storage Scheme will help the looming energy crisis; **Below:** Figure 1 location of Ingula Pumped Storage Project, South Africa

could be viewed as being dominated by its significant and complex underground works – there are more than 40 tunnels and shafts. The main underground structures are the headrace, penstock, draft tube, tailrace and access tunnels; surge shafts and chambers; and, powerhouse and transformer caverns.

Running from Bedford reservoir are a pair of approximately 2.1km long twin headrace tunnels with surge shafts where they break gradient, mid-route, to run more steeply down to the powerhouse.

Each tunnel splits in two to take a feed to one of two adjacent pump-turbines in the 186m long machine hall, which has a span of 26m and is generally 49m high, and 55m at the deepest points. Adjacent, and sitting parallel, is the 176m long by 18m wide transformer hall.

The 2.3km long, 9.4m i.d. concrete-lined tailrace tunnel, which features two 109m high surge chambers, takes the discharge from the pump-turbines to Bramhoek reservoir. It also is the initial conduit for flows being pumped back up, via the powerhouse and headrace tunnels, to the upper reservoir.

Ingula's two dams are themselves major structures – the 38m high by 310m long roller compacted concrete (RCC) dam at Bramhoek, which required 10m deeper foundations in some areas due to heavily jointed dolerite, and has a 40m wide spillway to pass flows of 715m³/s; and, the 51m high by 810m long concrete faced rockfill dam (CFRD) at Bedford, which has a spillway to discharge 200m³/s.

The 11.5km² catchment is small in relation to the size of the dam for the site, and runoff is low compared to live storage, but the spillway has been sized big enough to handle problems with the complex should the reservoir be already full. Generally, therefore, all normal floods will be discharged through the outlet works at flows of up to 50m³/s.

"Both dams are complete," says Sawyer. The upper reservoir "is waiting for completion of the headrace tunnel intake works before this area can be flooded."

Then, final filling of the reservoir will be done by pumping water up through the tunnel system from the Bramhoek pond – already fully impounded – during the commissioning phase, in 2014.

Geology

The area comprises horizontally bedded mudrocks, siltstones and sandstones of the Ecca and Beaufort Groups. The sedimentary rocks have been intruded by

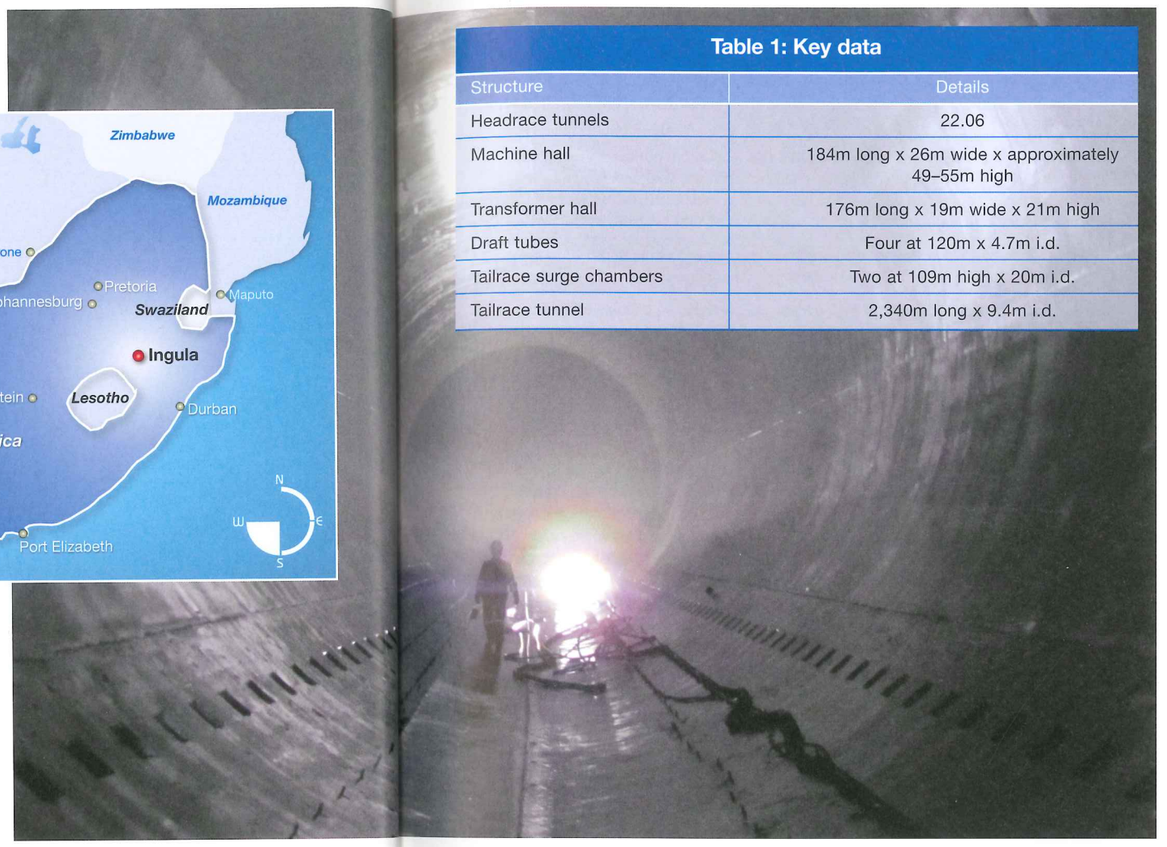


Table 1: Key data

Structure	Details
Headrace tunnels	22.06
Machine hall	184m long x 26m wide x approximately 49–55m high
Transformer hall	176m long x 19m wide x 21m high
Draft tubes	Four at 120m x 4.7m i.d.
Tailrace surge chambers	Two at 109m high x 20m i.d.
Tailrace tunnel	2,340m long x 9.4m i.d.

dolerites of the Karoo Dolerite Suite.

Powerhouse complex

The powerhouse caverns are located in Volksrust Formation mudrocks, overlaid by about 25m of Normandien Formation siltstones and sandstones of the lower Beaufort Group, and shale, then there is a 40m thick dolerite sill.

The thermal effects of the igneous intrusion altered the mudrock into the massive shale with relatively good uniaxial compressive strengths. Rock farther – deeper – from the sill was, therefore, relatively poor to fair.

Excavation of an exploratory tunnel to the area of the powerhouse complex was completed in early 2007 by Murray & Roberts (Concor). More than 60km of access roads were also built during the Stage One works.

While the undisturbed rock mass at powerhouse level is relatively unjointed, above the machine hall crown were a number of bedding parallel shear zones, identified during site investigation by boreholes and underground excavations in the area.

The infill to the planar contacts comprisied thin calcite stringers in a soft, brecciated, mylonitic matrix. The shears are offset where intersected by faulting. In the access tunnel excavations the intersected faults compised a zone of slickensided and striated joints, infilled with calcite and/or mylonitic, healed amorphous caclite. A few of the fault planes intersected the east end of the transformer cavern.

There is also a sub-vertical, sheared and faulted dolerite dyke that obliquely intersects the powerhouse area and main access tunnel.

Bedding and jointing was shown by modelling to have an overriding influence on stability and deformation of cavern excavations, requiring detailed investigations into strength, stiffness and orientation of the discontinuities to assist the detailed design.

Long-term creep tests were carried out on rock in uniaxial compression under a range of humidity and temperature conditions. The results confirmed that creep would occur in mudrocks due to changes in insitu stress, but the primary and secondary phases would be over relatively quickly. The results were later corroborated by plate bearing tests and monitoring data during tunnelling.

No groundwater issues were anticipated for the stability of the Ingula powerhouse cavern excavations.

Headrace and tailrace tunnels

In terms of engineering design of the underground works, one of the aspects of tunnel design at Ingula was insitu rock stress being less than water pressure in the headrace. Insitu stress measurements were taken by various techniques, including hydraulic jacking/ hydrofracturing, fracture opening and shut-in pressures. The specialist site investigations were conducted in 2006 and 2008 by Golder Associates and MeSy, and confirmed relatively low horizontal in situ stresses.

The rock stress conditions call for the steel lining to be used along the headrace as far up as the surge shafts. However, the sloping alignment helps to reduce the length of tunnel exposed to the overpressure and, hence, the tonnage of steel needed.

At Ingula, the steel-lined length of each of the two headrace tunnels approximately 1,060m long at 5.1m i.d., and the remainder, above, is 6.6m i.d. with SCL.

However, tunnelling on a slope is more challenging in comparison to the likes of the nearby Drakensberg pumped storage scheme, which was constructed by Eskom in the 1970s.

At the Drakensberg site, the insitu rock stresses are high enough to confine the high pressure from the water in the headrace, enabling most of the tunnel to be lined with concrete. Also, with the alignment having long vertical shafts and horizontal tunnels, the tunnelling work was relatively more simple.

Design and construction

The main civil package and main generation plant contracts were awarded in 2008. Early works, including advance infrastructure, more access roads and access tunnels – including a spiral extension of the exploratory tunnel to the operating floor level of the powerhouse – were completed between 2008 and 2009. Most tunnels were of horseshoe-shaped cross sections.

At a gradient of 1:10 and opened by drill

and blast, the main access tunnel is up to 9.5m wide, and tunnel junctions have 10 to 14m spans. Five classes of support were used in mudrocks, three in dolerite, and comprised steel-fibre reinforced shotcrtete and 4m long rockbolts, typically, plus arches at the portal.

To check for delayed convergence during excavation, a number of points along the 5m wide spiral access tunnel, extended down to the powerhouse level, showed it took three to four months for primary and secondary creep to end at the crown. The data was in line with results from the plate bearing creep tests. Tests of intact cores had indicated much shorter periods, but they did not have the larger rockmass weaknesses of bedding and joints. The creep is relatively insignificant long term, after the first four months, but suspended floors on corbels were chosen for the machine hall to avoid load transfer. Also, the crane beams will rest on columns and not be held by ground anchors.

A curved profile was selected for the powerhouse cavern roofs – double-radius arches, like the project's surge chambers which were of the same large span as the machine hall. The arch was chosen over a trapezoidal roof as modelling showed little difference in performance, but the latter induces bending moments in shotcrete, which would affect the timing and sequencing of construction work while convergence is awaited.

Modelling established the best plan for cavern excavations as a central heading with simultaneous side headings for the crown to be followed with a series of benches. But with delays to stabilising displacements in the adjacent spiral access tunnel, and the main access tunnel, the central headings were pushed ahead alone in the machine and transformer caverns, helping to confirm ground conditions.

Excavation support was provided by grids of primary rockbolts and cable bolts, and then secondary cable anchors further back from the face and with twice the load capacity at 60 tonnes. The cables were later grouted after some elastic convergence of the rockmass, and yielding of the primary support accepted with secondary support in place. Fibreglass dowels were installed in the floor and walls of the central headings to reduce heave and minimise effects on roof arch stability.

With permanent ground anchorages placed closer to the face than originally designed, convergence of the machine hall roof was less in the central heading, though in the side headings were in line with predictions.

In late 2009, an area of over break extended more than 2m as blasting progressed over a few days, and cracked some shotcrete areas too. Extra support measures included: full column grouting of installed rockbolts; installation and grouting of cable bolts up to the face; steel fibre reinforced shotcrete plus mesh; installation of cable anchors near to the face of side heading; and grouting of voids behind the cracked shotcrete.

Overbreak was generally to do with geology and not blasting.

The machine hall also has a central loading bay, added as buttress support the high rock walls in the cavern and minimise displacement between the turbine pits.

Distances between the large cavern, chambers and anchor galleries were large enough to prevent interaction and stress interference in the rockmass pillars seperating them. The distance between the machine and transformer caverns was increased from 35 to 40m to achieve this. But due to the many smaller tunnels and shafts in the layout around the large structures, extra strengthening works were undertaken around junctions, which saw steel arches placed at close centres.

The four draft tubes were raise bored as there were tunnels below for access and collection of spoil. The excavation commenced with 2m diameter pilot bores downwards, at 60 degrees inclines. Then the raised bores expanded the diameters to 6m as the debris fell down the pilot tubes to the tunnel below.

Raised bore excavation was also used for construction of the smoke extraction and ventilation shafts.

Six classes (A-F) of support were used for the tunnels and inclined shafts. The headrace was excavated uphill by drill and blast at a 'challenging' one in 2.2 slope.

As project construction got underway it was anticipated that the scheme could be finished in early 2013. By early 2011, in a presention to the BTS, the project parties were viewing the completion schedule as 2014. The latest view is a finish a few months later, early in the following year.

Finding the storage site

Early planning studies for a potential pumped storage addition to South Africa's electricity assets began in the mid-1980s. From approximately 90 sites that were identified as having potential for a large project the list was whittled to seven preferred sites – Hogsback, Impendle, Waayhoek, Ingula, Tubatse, Strijdom and Mutal.

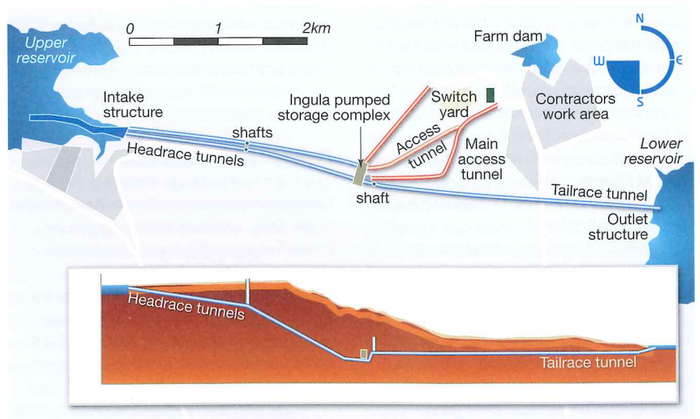
The elected site, Ingula, is located within the Little Drakensberg mountain range, across an escarpment which is the continental watershed between the Vaal and Tugela river basins that are major sources of water in the country. The escarpment is between the Free State and KwaZulu Natal provinces.

The Lesotho Highlands Water Project was originally envisaged to transfer flows to the Vaal basin, and the Ingula scheme is the next stage of that sequence.

The area features wetlands, peatlands and wildlife, concerns over all of which resulted in opposition and environmental questions when the scheme was first approved in 2000. To help mitigate the environmental impacts, the project purchased additional land to manage as the Bedford Wetland Park.

Further aspects that have required plans incude the socio-environmental factors of historical artifacts, such as bushman paintings and and relics, and recovery of fossil animals and plants, such as examples of the Dicynodont and a Glossopteris tree, dated to around 255 million years ago.

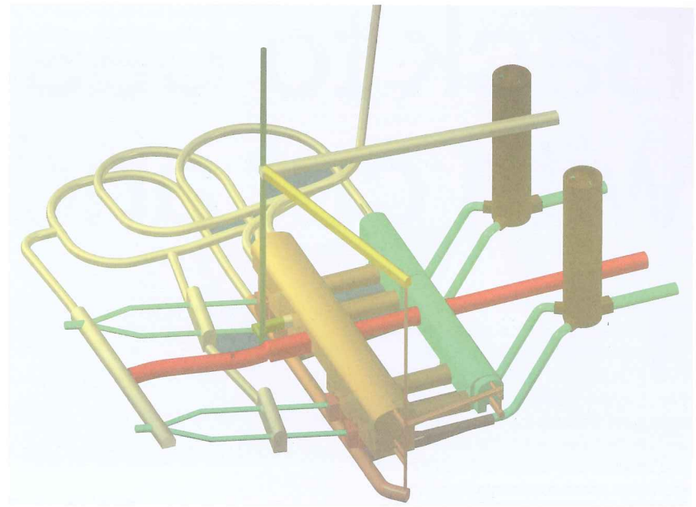
Below: Figure 2, layout of Ingula Pumped Storage Scheme



Final stages

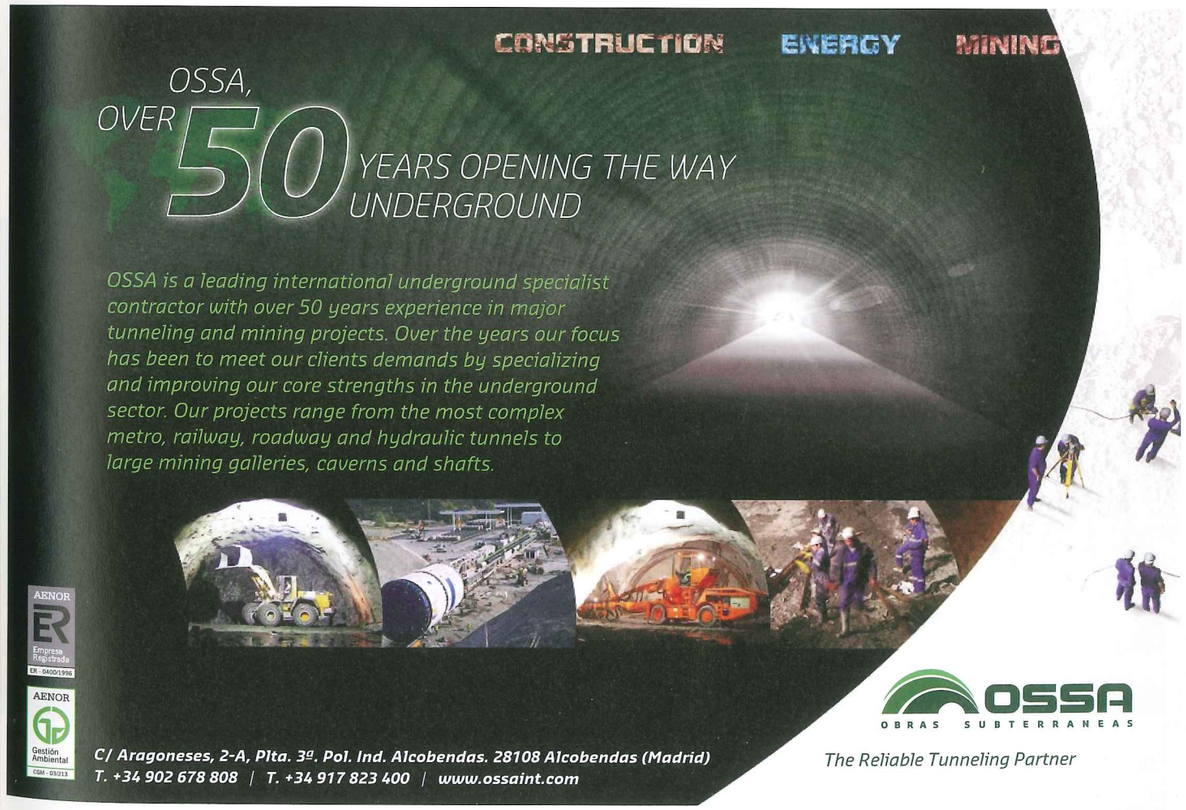
Unusually for either a hydro or pumped storage project, much of the waters were impounded way before the tunnelling was even nearly finished, though not by design. Three years had been allowed for the Bramhoek reservoir to fill but, due to hydrological surprises, it was achieved in barely a few months.

Tunnel and cavern excavation is now virtually complete, with some shaft excavations still ongoing, says Sawyer. Construction works and plant installation in the machine hall will continue into 2013.



Above: Figure 3, schematic of Ingula underground powerhouse complex

Concrete works and installation work have started at the draft tubes. He adds that the main cranes (two x 265 tonne) have been installed and are being commissioned, to be ready for installation of the generation plant.



Back to basics with cut and cover

Cut and cover. Bachy Soletanche UK's director Chris Merridew and business development manager Paul Hodgson get back to basics on the cut part of the method, while Alex Conacher speaks to Bernhard Lindner of Germany-based Peri about the concerns of formwork manufacturers in providing the cover

The cut and cover technique has been used successfully for shallow tunnelling and deep tunnel portals for many years utilising a host of different techniques to retain the in situ soils in cut to allow the cover to be constructed. These have been cost effective alternatives to bored tunnels and where space constraints in an urban area restrict the use of large open earthwork cuttings. Bored pile or diaphragm walls offer an effective retaining system for the 'cut', enabling cut and cover tunnels to be constructed safely, close to neighing structures. As the cuts get deeper the technique will change as the required wall verticality improves.

System

Cut and cover tunnels can be constructed in one of two ways. These are bottom up and top down.

Bottom up is the simpler system, where the walls are constructed, excavation of the box is carried out, the base is installed and the cover or permanent props are constructed.

Top Down involves the walls being constructed, shallow excavation carried out, cover or permanent props constructed, excavation completed and then the base installed. Excavation may be slower and more expensive, but this may deliver benefits to the main project programme.

Techniques

Contiguous piled walls are piled walls installed in a sequence with a gap between the piles to avoid damage to neighbouring piles. This limits their use to soils that will not fall out during excavation and where the water table is below the invert of the tunnel or can be controlled during excavation. Contiguous walls are faster and cheaper to install than secants but have some limitations. They can be installed using high productivity continuous flight auger (CFA) rigs or high power rotary rigs. This technique was chosen for the major part of the Thames Link Box at St Pancras Station in London as it offered programme saving during a demanding blockage period.

Secant piled walls are normally the preferred system of piled walls that interlock or secant together to form a stable wall with a high level of water tightness.

These are also installed in sequence with the primary or female piles installed first, followed by the reinforced secondary or male piles that cut into the primary piles. The concrete used for the primary piles tends to be a weaker mix than the secondary piles, giving rise to the terms hard/soft, hard/ firm or hard/hard walls. These can be installed using high productivity CFA rigs, high power rotary rigs, or more recently high power and high productivity cased CFA rigs, which have enhanced verticality tolerances.

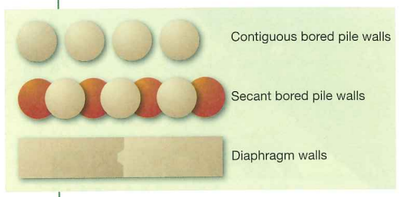
Diaphragm walls are a heavy-duty wall that tend to be employed where a stiffer wall is required or where the depth of wall precludes use of secant piled walls due to the verticality and depth. Current methods use rope or hydraulic grabs, or hydrofraise/milling techniques. All three methods require a bentonite support fluid or similar. Low headroom rigs are available if work is required under existing structures. The technique used will depend on the depth/verticality required but, as ever, has cost implications, with more technical systems costing more.

Sufficient space on or near site needs to available for bentonite de-sanding and storage; productivity can be reduced if sufficient space is not available.

Alternatives

Other successful cutting solutions have included modular systems such as reinforced earth panels and precast arches such as Techspan, that were used successfully in the UK on a number of contracts on the CTRL project.

Below: Figure 1, retaining wall types



Below: Diaphragm wall and props from the Tyne tunnel project, UK

Wall Propping

With all cut and cover works, temporary propping needs to be considered, as this may be required until the 'cover' is in place. The cost and inconvenience of the propping system needs to be compared with thickening up the piled or diaphragm walls to stand unsupported in cantilever. These props can be anchors, raking or horizontal props.

History has shown that this subject is ignored at one's peril.

Formwork and 'the cover'

Formwork making up the temporary props and frames is put in place during the casting of the in situ concrete. This will form the 'cover' part of the construction.

Usually mounted on a carriage on runners, the formwork array is moved along the alignment as each concrete element of the tunnel section – including base plate, walls and slab – is cured.

These three elements of the completed tunnel can be cast separately and sequentially, or in different semi-monolithic combinations depending on requirements.

As an example, one semi-monolithic combination is trough construction. In this, instead of advancing ahead with the base plate, following with the walls and then finishing with slab, the walls and base plate are cast as one unit.

The purpose is to ensure absolute water tightness, removing any risk of ingress through the joints between base plate and wall. The wall formwork would hang on a portal carriage encompassing the width of the tunnel. The slab formwork follows afterwards on another formwork carriage.

Formwork on Strasswalchen tunnel project, Austria

Formwork loads

Mobile or crane-movable formwork is used for the walls, depending on the length of the structure. Wall formworks are normally designed for a fresh concrete pressure of 60kN/m². Slab formworks are designed for the formwork self-weight and wet concrete load and live load.

Rental market

Some 80 to 90 per cent of the formwork to a cut and cover project is rented. This makes the treatment of the materials very important. Bernhard Lindner of Peri says, "There has been a tendency in the Middle East to not return rented equipment, and rather face the charge for that. This is mostly on high-rise projects, and the cost for returning the formwork damaged could be equal to two to three year's rental cost.

Lindner adds that heavy steel equipment treated well could last 20 to 25 years. Site conditions are so important that design life calculations are only done for financial forecasts. Eight to 10 years is assumed.

Options and concerns

For efficiency and quick movement along a project, the number of components making up the formwork is not of real importance to a contractor. Once set up, the loading and balance as well as the economic fitting of the carriage is the main influence on an effective advance along the alignment.

Despite this, Lindner adds that the number of components is a concern for Peri, but purely for warehouse stock keeping. The company's approach to formwork efficiency is to provide a product that can largely be reused, and also used on different types of projects.

Peri's 'Variokit' was designed to be used on bridges and other engineering projects as well as tunnels and is held together by special connecting pieces of formwork and either pins or threaded bolts. Peri pushes for the pin option as bolts have to be pre-tensioned and need to be scraped after use, so it is less desirable to rent them. Bolts also leave a slight gap in the hole, resulting in geometric deflections. Lindner adds, "We prefer pins because of this. You can get a stronger connection, and deal with greater loads."

Shifting

The movement of the formwork is an option for the contractor. Lindner says that in less developed countries there is a danger of unskilled labour damaging the hydraulic units that shift the carriage. Then there is the issue of expense. Usually in the same countries, manpower is cheap, meaning that the carriage is more likely to be pushed by hand, solving both problems. In more developed countries, hydraulic units can be used to raise and lower formwork, and move it along the rails.

Materials

Steel is the most economical material for heavy duty engineering props and other formwork with high loads. Aluminium heavy load bearing props with the same capabilities have been developed but the benefit of using lightweight props on the load is insufficient for use in tunnelling.

Lindner believes that this won't change in the next decade, and while companies are doing research into plastics, the loads are just too high.

Higher grades of steel are preferable.

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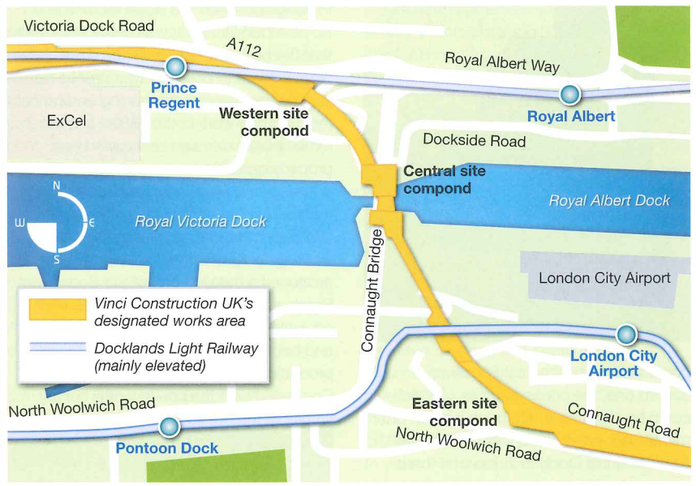
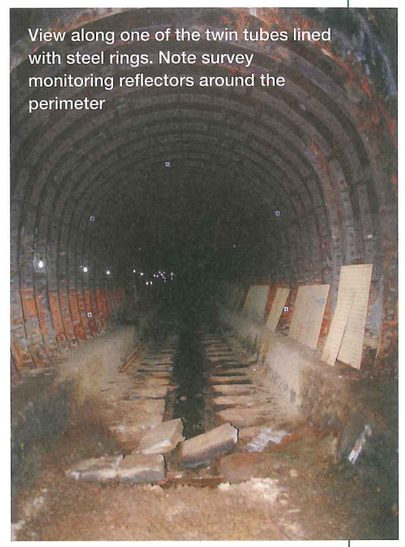
Crossrail planning dock breakout

When Crossrail took over the ancient Connaught Tunnel as part of its route through east London, it was envisaged that it would be brought up to standard with a fill and re-excavate procedure, but further site investigations led to concerns that will now be tackled by open excavation through the Royal Docks



Above: Figure 1, location diagram of the Connaught Tunnel between the Royal Victoria and Royal Albert Docks in east London



View along one of the twin tubes lined with steel rings. Note survey monitoring reflectors around the perimeter

T&TI last detailed plans for the reconstruction of the Connaught Tunnel over a year ago (see feature, *T&TI* June 2011 page 22) but even then it was recognised that continuing site investigation work on the state of the tunnel structure and unexploded World War II bombs possibly in the zone of influence could modify the original plans. It is likely no one envisaged how radical the modifications would have to be.

Contracts

The Connaught Tunnel is part of Crossrail contract C315, which was awarded to Vinci Construction UK along with the adjacent work on the railway route rebuild to North Woolwich on the north bank of the River Thames. This branch of Crossrail will then continue on other contracts to Woolwich and Abbey Wood through new Thames Tunnel. The route follows the route made free by the closure of the North London Line branch and national rail tracks to Custom House, closed in 2006.

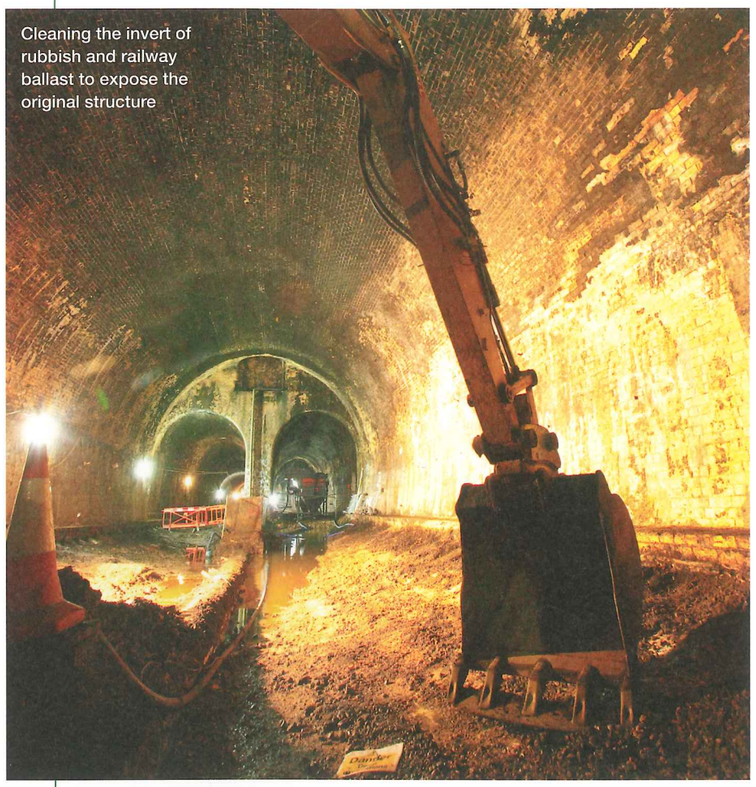
Contract C315 covers 2km of track of which half is the Connaught Tunnel, some of which is of open structure with brick arch buttresses. These lengths are being preserved, although the potentially unsafe structure of the tunnel itself cannot now be.

Vinci operates the sites under the trade name Taylor Woodrow which it uses for its civil engineering. The project manager is Paul Edwards. Project director for the client is Linda Miller; seconded to Crossrail from Bechtel (see feature, *T&TI* May page 80).

History

The Connaught Tunnel was first completed in 1878 to remove the bottleneck of having to use a swing bridge, the base of which still exists, for rail traffic to pass through the Connaught Passage between the two dock basins. Dock traffic grew rapidly and made this idea impractical. The tunnel is a twin-track, single-bore structure until it passes under the Connaught Passage where it splits into twin tubes, each 550m long, with a vertical ventilation shaft at each end.

The increasing size of cargo ships needing to use the docks meant that the Connaught Passage into the Royal Victoria Dock needed deepening in the 1930s. In order to preserve the tunnel structure the alignment was lowered (see feature, *T&TI* June 2011 page 22) and full-circle steel


Cleaning the invert of rubbish and railway ballast to expose the original structure

rings installed, interlocking with each other to form a binocular profile. This was an early use of structural steel underground.

The tunnel has been used for both freight and passenger traffic, the latter most recently using third-rail electrification, evidence of which has now been removed. In addition to its long-term workaday duties, the Connaught Tunnel has also appeared in a feature film – Guy Ritchie's 'RocknRolla' in 2008 after rail closure.

Preparation

One of the first tunnel jobs has been the removal of old rail infrastructure, ballast and debris to exposure the brick-built invert with ribs. Once cleaned, inspected and grouted, structurally sound arches are being preserved in the approaches and single-tube sections of the tunnel.

The old Silvertown Station on the same route and contract is being demolished.

London's Docklands was a main target of bombing in World War II. Although maps have been compiled of known locations, due mainly to the spotting activities of ARP wardens during the Blitz, there is still a strong possibility that any underground construction activity might uncover or disturb one, the consequences of which could be disastrous. Although it is not often mentioned, previous tunnelling works in east London's Docklands have hit them before. Therefore specialist contractor Fugro undertook a survey of the ground adjacent to the rail route lest any bombs might be disturbed unwittingly. Freely available mapping data, and the use of sophisticated instrumentation such as magnetometry and ground-probing radar have made the task a bit easier, but not without risk.

Despite a direct hit on the tunnel, necessitating repairs to the brick lining, the tunnel crown structure held together, even though other bombs fell in the vicinity.

Sonar shock

One of the survey measures taken during site investigation was a detailed sonar survey of the passage of the existing Connaught Tunnel under Connaught Passage between the Royal Victoria and Royal Albert Docks. It was know historically that the bottom of the passage would have been subject to possible interference from larger ships, despite deepening and tunnel restructuring work in the 1930s, but the extent of any damage had never been properly quantified.

Using a relatively new multi-beam sonar method carried on the special vessel 'Galloper', the Port of London Authority, working for subcontractor Abwood, produced a detailed plot of the Connaught Passage. The system employs the equivalent of 512 probes, including side and back echo measurement, and producing a multitude of measurements. Compared with the conventional survey results of the tunnel interior, this showed that the tunnel cover was much less than expected including a potential area of

Below: **W J Groundwater crew adjusting the position of a Klemm rig used for boring dewatering wells The location is the limited space between the Connaught Bridge and the 130-year-old pump-shaft head-house**

breach. According to project manager Paul Edwards, at the worst point the cover was only 300mm, and that was broken concrete. So the risk of inundation was substantial even before reconstruction.

Since it is necessary to enlarge the passage for the new Crossrail rolling stock it was decided that the risks involved in underground work were too great, if not impossible.

Abwood is providing a number of other support services to the project as subcontractor including marine divers, surveyors and silt removal. Among the debris found in the docks are some of the legendary 'over 100' cars, although all have already been inspected by police.

Water, water

"The high water-table can be a nightmare," says Linda Miller. Despite its upper parts resting in clay, the original tunnel has a long history of leaks, whether from the docks or the underlying mark. The groundwater pressure on the brickwork has been controlled by a permanent drainage and pumping system, currently still in use.

The natural geomorphology of the area is a swamp, in close proximity to the River Thames, so all drainage has to be artificial. There are also tidal effects on groundwater pressures. Whilst a bed of clay is present at the tunnel horizon, it is overlain by an Upper Aquifer of river terrace gravels, and underlain by marl.

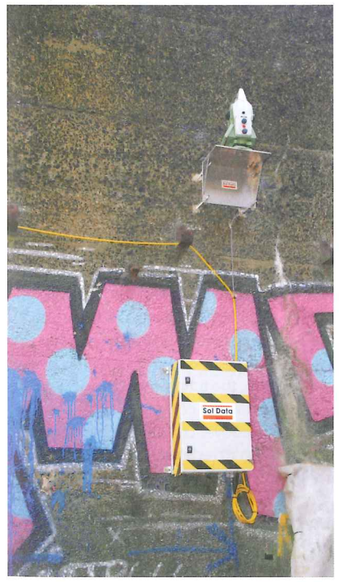
A large proportion of the project is concerned with water control in various forms, especially as the cofferdam excavation has to be kept dry for the new temporary works.

Specialist contractor WJ Groundwater has been installed dewatering wells around the Connaught Passage to lower the watertable, and carrying out pumping tests to determine groundwater flows. Lowering of the watertable will also allow the deepening of the existing pumping shaft.

As well as minimising water nuisance and making construction practical, it will also reduce groundwater pressures. This is particularly relevant in connection with old structures such as the existing tunnel and dock-walls, the condition of which has not yet been fully determined. The construction designers have requested continuous monitoring of water levels and pressures.

The new permanent drainage arrangements will include a new connection, probably microtunnelled, from the new tunnel sump to the pump-house shaft, which will have been deepened by a further seven metres to 25m.

Four larger units will replace the existing pump range of three units. The space required for installation and future maintenance means that the existing Victorian pump head-house is too small. Although final negotiations are still under way it is intended that it will be dismantled brick by brick and donated to the Newham local council for re-erection adjacent to the intended mooring of a preserved steamship, the SS Robin, perhaps as a ticket office.



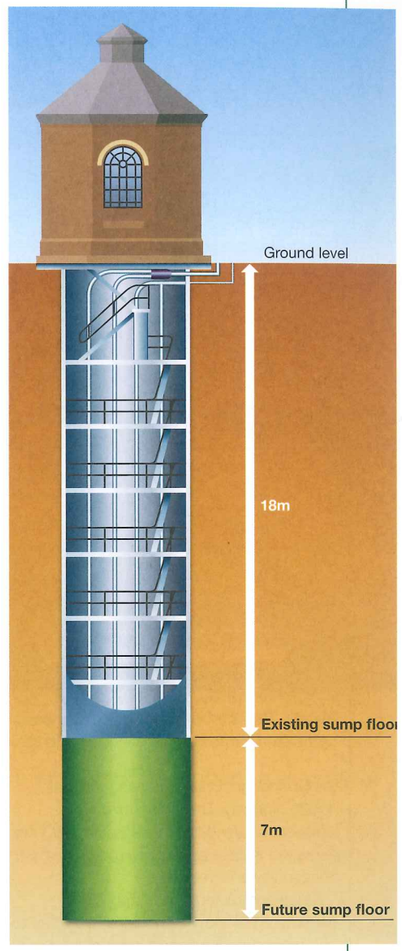
Strengthening

In view of uncertainties about ground behaviour when it is subjected to changes in water levels and pressures, it is being 'stiffened', by the Soletanche Freysinnet group, with a series of 3,000 controlled modulus columns (CMC) so that the behaviour can be better predicted. The columns are excavation by specially designed auger-borers and are pumped with PFA grout.

A similar operation had been undertaken in equivalent conditions in the area for the Channel Tunnel Rail Link excavation (HS1).

Reflecting the original method of construction, the new Connaught Tunnel will be built by cut and cover methods, necessitating the use of cofferdam through the Connaught Passage. Such reconstruction will also allow the tunnel to be deepened and enlarged more easily.

Left: **One of Soldata's many structural instrumentation points for the tunnel including a Leica motorised theodolite**



Above: **Figure 2, the pump house shaft will be deepened to 25m**

Cofferdam

Agreement was reached to avoid disrupting the 2013 London Boat Show, which is held with many visiting boats and ships in the Royal Dock. Consequently installing of the cofferdams in the Connaught Passage will not commence until February 2013. Although this will allow plenty of time for ground reinforcement work and work on the tunnel approaches, it also means that all works have to be competed within a six-month period in order to stay of schedule.

The cofferdam across the narrow waterway will be formed with two rows of interlocking sheet piles filled back with grouted sand and gravel. They will stretch approximately parallel with the pedestrian bridge over the passage and to the east of

Above: The footbridge over the Connaught Passage which will be the site of the cofferdam. Note the old swingbridge structure to the left

the Connaught Bridge carrying the main A1020 highway. This presents quite a logistical challenge to manage the site, with restricted access and space available, both horizontally and vertically.

Once completed, the temporary cofferdam will allow the water in between to be pumped out and excavation of the remaining ground and removal of the tunnel steel rings to take place. Excavators can be mounted on the dock wall and cofferdam themselves. As the ground will have been strengthened, pressure on the dock walls will be minimised, but the excavation will also be supported with temporary struts.

Archaeology

Another non-construction factor that has to be considered is the ancient history of the area. Provision for allowing archaeological 'digs' before covering with new construction is built into all relevant Crossrail contracts. The rail route being refurbished actually follows an old Roman road, which in its turn is also believed to have followed a prehistoric pathway.

Consequently there are digs going on at selected sites on the route. A recent press visit was unable to visit the excavations for safety reasons as they had uncovered an unmapped 10kV live electrical power cable. The high water table also interferes with archaeological excavations as well as the main tunnel work. Nevertheless, evidence of settlements dating back 6,000 years has been found.

Community and environment

All work is subject to planning and environmental restrictions, especially in view of the residential, commercial and transport link nature of surrounding properties. Excluding setup and shutdown periods, normal working is from 8:00 to 16:00 on weekdays and 08:00 to 13:00 on Saturdays. All compound areas are surrounding by high hoardings that are also said to have the effect of reducing dust emission. Both this and noise controls are in force.

There is liaison with the London Borough of Newham local authority on environmental as well as official planning matters. The change to cofferdam construction has resulted in the need to apply to extend the extent of the working area slightly around the Connaught Passage to allow for the extra surface equipment required.

There also needs to be liaison with a wide variety of other stakeholders, especially in the London Olympics year and with the wide variety of other construction work going on in London's Docklands including, it was jokingly said, the fish in the docks.

Last year the Vinci Construction UK team at the Connaught Tunnel won a silver award in the UK's independent Considerate Constructors Scheme. This is an industry run initiative that assesses and monitors sites against a code of practice, and commits them to being clean, respectful, safe, environmentally conscious, responsible, accountable and, overall, a good neighbour.

Progress

The contract sites were mobilised from April 2011 with the main work commencing at the end of September last year. Work on the surface route, both civils and railway work, has been progressing well since commencement. Following extensive site investigation, the tunnel itself has now been cleared, and water control measures being installed as above. Despite the changes in the approach to reconstruction, the contract is still understood to be on schedule, although on the critical path, with the tunnel due for completion by October next year. Connaught Tunnel scored 36.5 out of 40 points compared to a UK average of 31.

NTA
The Israel Light Rail

NTA - Israel Metropolitan Mass Transit System Ltd

Tender No. 060/2011 – Pre-Qualification Requirements

For the design, supply, construction, installation, integration, testing and commissioning of Systems – Depot – At Grade (SDAG) for the Red Line Project

1. N.T.A. – Metropolitan Mass Transit System Ltd. ("**NTA**") is an Israeli governmental owed company in charge of the design and construction of the mass transit system in Tel Aviv metropolitan area.
2. The Red Line is the first Light Rail Transit line of the Tel Aviv metropolitan area mass transit system to be implemented and is approximately 23km long, out of which 11.5km are at grade level and 11.5km are underground **("Red Line").**
3. NTA wishes to retain contractors to provide the design, supply, construction, installation, integration, testing, and commissioning of the Systems, Depot, At Grade works for the Red Line.
4. At this first stage of the Tender, the pre-qualification process, NTA will review the compliance of participants who are skilled international Rail Transit contractors with the requirements detailed in the pre-qualification documents (the **"SDAG PQ Invitation"**), including, without limitation:
   - Integration and Interface management, program management and construction management experience in rail transit projects.
   - Design experience of rail transit projects.
   - Systems supply and installation experience in rail transit projects.
   - Depot construction experience.
   - Civil engineering experience, including registration pursuant to the Israeli Registration of Contractors for Engineering and Building Works law, 5729-1969 in the relevant fields and classifications or equivalent laws and regulations abroad.
   - Financial solidity.

   The above mentioned pre-qualification requirements are not exhaustive and were described in a general manner, and are subject to the provisions of the SDAG PQ Invitation.
5. Only eligible participants in accordance with the provisions of the SDAG PQ Invitation shall continue to the second stage – the tender process and will be entitled to submit a bid including, without limitation, the quality and the price offers.
6. As of June 28th 2012, the documents of the SDAG PQ Invitation may be produced by download from NTA's website at: http://www.nta.co.il/site/en/neta.asp?pi=464 or from the following file server: http://ftp.nta.co.il (login:ftpuser17, password: Sdag@13).
7. A pre-qualification conference shall be convened by NTA's Tender Committee on July 17 2012 (further details shall be published on NTA's website). For the avoidance of doubt, the participation of the participants or their authorized representatives, in the pre-qualification conference shall be mandatory. Participants are required to send the Tender Committee the details of their representative(s) in the conference at least seven (7) days prior to the conference. Such notice shall be sent by e-mail to the address detailed below.
8. All questions regarding the SDAG PQ Invitation may be addressed to e-mail address: SDAG_Tender_060_2011@nta.co.il (link: SDAG_Tender_060_2011@nta.co.il), until August 7, 2012.
9. The pre-qualification submissions shall be submitted to NTA's head offices located at 132 Menachem Begin Rd, Tel Aviv, Israel Azrieli Towers, the Round Tower Floor No. 16 (an ID card is required in order to enter the building and NTA's offices), on week days, Sunday to Thursday, during opening hours 09:00-17:00 (Israel time, +2 GMT) no later than August 20, 2012, at 17:00, Israel time, +2 GMT (and not earlier than seven (7) days prior to this date).
10. It is hereby clarified that if a contradiction is discovered between this announcement and the SDAG PQ Invitation, the content of the SDAG PQ Invitation shall prevail.

Itzhak Zuchman
CEO N.T.A.

ASHKENAZY ZALSMAN / BSB

www.nta.co.il

The Israel Light Rail

NTA, Israel Metropolitan Mass Transit System

Tender No. 017/2012 - PQ

For the Design Build of NATM Tunnels for the Tel-Aviv Metropolis RED LINE

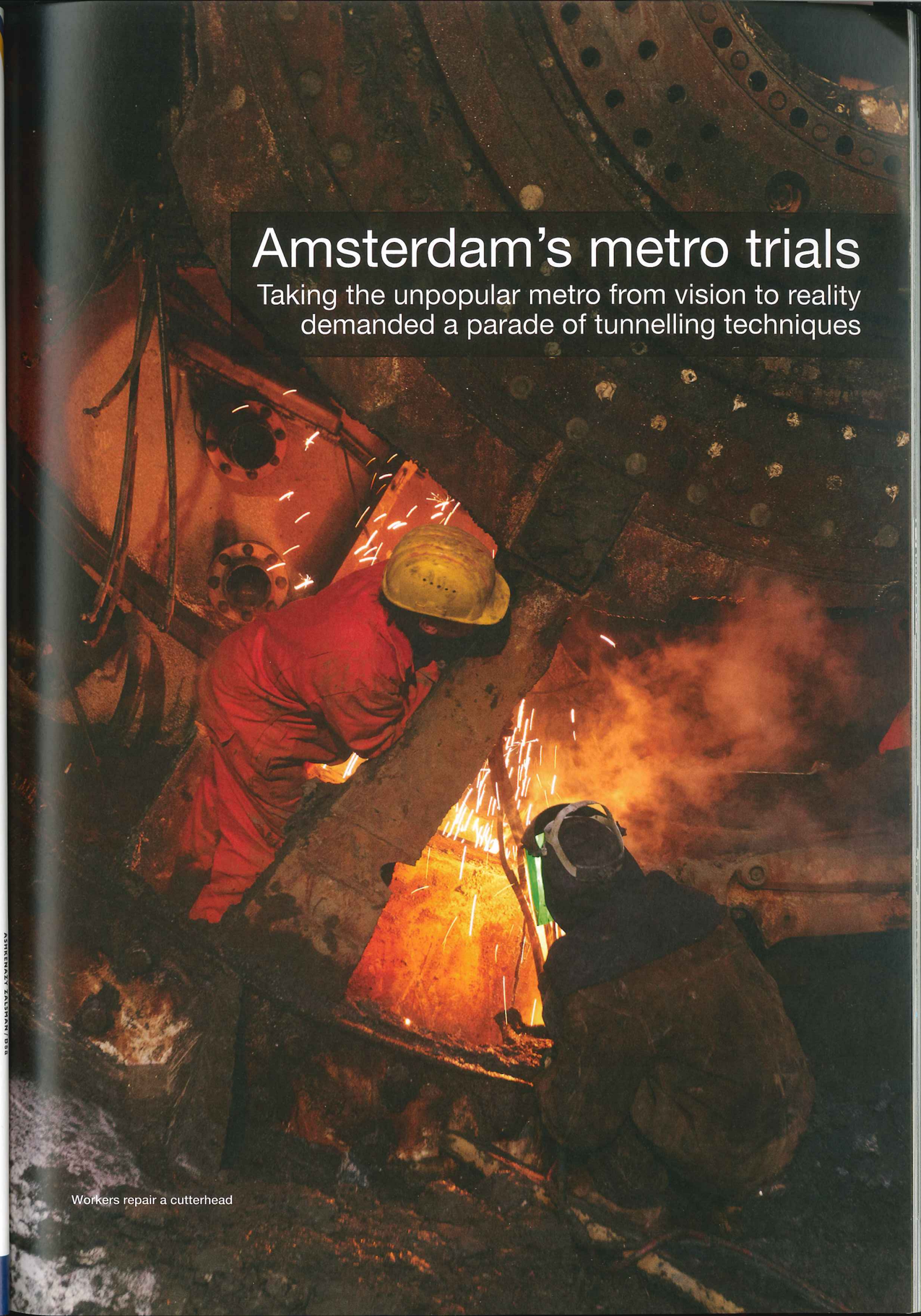
1. NTA Metropolitan Mass Transit System Ltd (**"NTA"**) is an Israeli government owned company in charge of the design and construction of the mass transit system in the Tel Aviv metropolitan area.
2. The Red Line is the first Light Rail Transit line of the Tel Aviv metropolitan area mass transit system to be implemented (**"Red Line"**).
3. The Red Line:
   - 3.1. The overall length of the Red Line is approximately 23 kilometers.
   - 3.2. The central section of the alignment will be underground, and shall be comprised of cut and cover sections, shield TBM bored tunnels and NATM tunnels.
   - 3.3. The mined tunnels (NATM) are approximately 1.5 kilometers long, consisting of twin mined single track tunnels with cross passages and three Chambers (total of approximately 3.5 Km).
4. NTA wishes to retain tunneling contractor to provide design-build services for the NATM mined tunnels for the Red Line, including the mining of cross passages, the chambers and certain post Tunneling works as will be further described in the Tender documents.
5. NTA anticipates that the works to be implemented pursuant to the tender process (which may be published following this NATM PQ Invitation), shall be performed during a period of approximately three (3) years (which may be extended). NTA, at its sole discretion, may determine different period for the performance of the works. All details in that respect shall be specified in the tender process.
6. At this first pre-qualification stage of the Tender ("PQ") NTA will review bidders' qualification with the threshold requirements detailed in the PQ documents, including without limitation, certain tunneling experience requirements, certain design experience requirements and certain financial requirements.
7. Only qualified bidders shall continue to the second Tender stage and will be entitled to submit the quality and price offers.
8. The Tender documents, including without limitation, all prerequisites for participation in the Tender, may be produced by downloading them, as of June 28th, 2012 from NTA's website at: **http://www.nta.co.il/site/en/neta.asp?pi=464** or from the following file server: http://ftp.nta.co.il (login: ftpuser118, password: A1122z).
9. A mandatory bidders' conference shall be convened by NTA on July 30th, 2012, 09:00 Israel standard time, at a location in Israel to be determined by NTA. For the avoidance of doubt, a proposal submitted by any bidder which did not participate in the bidders' conference as abovementioned, shall be disqualified.
10. All questions regarding this Tender may be addressed to the Tender's email address at: tender017_2012@nta.co.il (Link tender017_2012@nta.co.il)
11. The PQ proposals shall be submitted to NTA and will be deposited into NTA's Tender box, Azrieli Center – Round Tower, 132 Menachem Begin Road, 16th floor, Tel Aviv 67021, no later than September 27th, 2012 at 17:00 Israel standard time. Bidders shall receive written confirmation of their submission.
12. It is hereby clarified that this notice contains only general and preliminary information regarding the Tender and the PQ process, and should any discrepancy be found between this notice and the Tender documents, the content of the Tender documents shall prevail.

Itzhak Zuchman
CEO N.T.A.

www.nta.co.il

Amsterdam's metro trials

Taking the unpopular metro from vision to reality demanded a parade of tunnelling techniques



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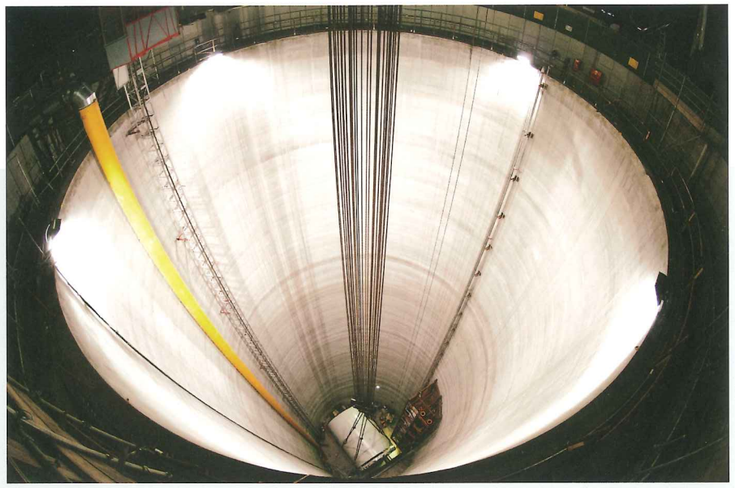
Workers repair a cutterhead



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A mixed approach to metro construction

Engineering innovations, tenacity and skill are finally bearing fruit on the extraordinarily difficult North-South line metro project in the historic city of Amsterdam. Technical writer Adrian Greeman gives this report from Holland

Formwork errection for casting of the tunnel eye ahead of TBM launch

The Shield Transfer System was key to progressing TBM tunnelling through the stations (see feature, page 40)

The word metro is a delicate one in Amsterdam. Construction of the east-west line in the 1970s triggered huge opposition as buildings and neighbourhoods were demolished. The post-1960s protest movement turned its attention to environmental and green issues. There were riots.

So it was not until the early 1990s that anyone dared breath a word about a North-South Line. It was even more contentious given that it would pass underneath the historic centre of the city - a world heritage site and a major tourist attraction.

The new project was to avoid any past difficulties by using modern tunnelling methods, with some major innovations. It would pass underneath the city, leaving old buildings intact and unaffected.

Above: **Figure 1, the line will serve the Dutch capital of Amsterdam**

A host of techniques would be employed, almost a catalogue of modern tunnelling and ground engineering, from advanced real time TBM control, to refinements in compensation grouting and new methods of tunnel lining. An extraordinary and unique application of immersed tube tunnelling was combined with advanced jet grouting, and vertical microtunnelling to pass beneath the historic central station. Deep excavation with diaphragm walls could make the stations. There are even caissons.

Planners and designers believed modern techniques would make the work possible. But they all posed huge difficulties. The Netherlands is famously mostly below sea-level and most of its geology formed by glacial, marine and estuarine deposits, in other words soft, water-filled ground, setting major challenges for tunnels and ground works. For good reason bored tunnels were unknown in the country until the 1990s.

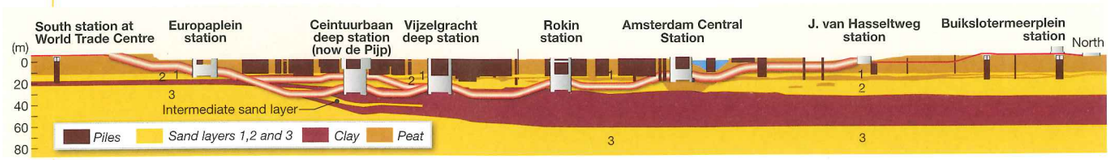
Within cities it was even more of an unknown and particularly in Amsterdam where the famous tall, thin, canal-side buildings are founded essentially in a peat bog. They are carried by tens of thousands of timber piles on to a sand layer beneath, all preserved by the water around them but vulnerable to atmospheric decay.

"The city geology is one of multiple layers," explains Frank Kaalberg, tunnel design project leader for the project's design consultant, Tunnel Engineering Consultant. The company is a joint venture between Dutch Witteveen+Bos and British Royal Haskoning.

Three layers of sand alternate with medium soft clays beneath the peaty top ground, he explains.

The first is the traditional founding for historic buildings, the second at roughly 40m depth is used for modern buildings and the third 60m down for a few very high rise modern towers. There is also an intermittently occurring sand layer between the second and third layers. In places, the main layers also disappear.

Below: **Figure 2, the geology is formed by glacial, marine and estuarine deposits**



Line route

The North-South line is needed to connect the important RAI congress and exhibition centre in the south of the city to the main station. Beyond that it provides a link to the isolated North Amsterdam area, rapidly developing but cut off by the wide Ij river. In general it expands transport capacity in a city with modern needs.

An initial 9.5km length will also offer expansion possibilities to Schipol airport eventually, further increasing the line's value.

The route begins in the new housing areas of North Amsterdam as an at-grade line with two stations. At the river Ij it drops into a cut and cover incline to a 500m long immersed tube crossing, which will be made this autumn.

This connects an extraordinary underground station made beneath the multiple arched glazed roof of the Central Station by forming a huge water filled cavern beneath a giant concrete slab now supporting the station and floating in an additional immersed tube section. The six year operation to build this space using new jet grouting methods and vertical micro-tunnelling was described last year in T&TI (October 2011, page 30).

The line runs on through three caissons, sunk in the waterways in front of the station, and soft ground beneath without the normal sand layer. They form a transition to take the line deeper into the main bored section which runs nearly 4km long through 'old Amsterdam'. The central section made by TBM has three huge underground stations, which have proved to be some of the most difficult work on the project.

Beyond that it rises again towards the surface in a short conventional cut and cover section before finishing once more at surface level alongside the rail station serving the Exhibition Centre.

Above: **Figure 3 the line runs from the south exhibition hall to new homes in the north**

The sand is firm but porous and delivers substantial water pressures underground to be coped with by any excavation or tunnelling. Hence the armoury of modern techniques and sometimes traditional techniques which have been required.

The challenges have been met, but with significant difficulties along the way; much of the work has been more demanding and time-consuming than thought originally. An infamous incident in 2008 saw leakage through a diaphragm wall, which damaged old weavers houses. Station work was suspended and the prospect of cancelling the whole project mooted.

But this nightmare low point in 2008 passed and the project turned around. One by one different underground techniques are proving their worth and the scheme is on an albeit heavily revised course. Even the notoriously prickly Amsterdam population has turned positive. Some of the damaged buildings have been repaired.

Cost of the scheme as currently estimated is over EUR 3bn (USD 3.8bn) against an initial estimate of EUR 1.4bn (USD 1.8bn) and the opening date has been put back by five years to 2017. But that now looks certain.

"There was a very closed culture for the project earlier on," says Gerard Scheffrahn, currently contract manager for the deep stations. He is a management consultant who came in after 2008 to try and help turn around a project which had become almost paralysed. "After the difficulties of the incidents, things were even more closed in, as everyone was highly defensive."

A big effort was made to change the atmosphere of the project to one of much greater transparency, both internally, and in the relations with the public. This began with an acceptance that the project should continue and that rather than assign blame for the difficulties, with potentially extended legal actions and potential breakdown, a compromise should be reached.

"There are many possible causes of the incident" says Scheffrahn," adding that he cannot comment on whether eventually there will be legal actions and claims.

"But for the moment that is to one side and a pain-gain contract arrangement was instigated to keep the project going," he says. Along with that came a complete restructuring of the management culture, including a beefing up of the city's management oversight team. New risk assessment methods were instigated and more detailed incident protocols and sign-off procedures.

"We began by bringing in a variety of European expertise for round-table sessions to examine the incidents and the general methods of the project," says Scheffrahn. "After these meetings, which brought in insurance representative as well, things started to move along better."

Amsterdam seems on course to achieve its North-South Line

Deep drives

The central element of the North-South line, in engineering terms and literally on the route line, is the bored tunnel section. Adrian Greeman visits the project

From the beginning it was supposed the most hazardous, contentious and difficult part of the North-South line. The underground tunnelling work through the old city centre of Amsterdam, a national and world heritage site, unique in the world, carried risk and public mistrust. In the event so far the TBM drives have gone exceptionally well.

A total 3.1km of 6.5m outer diameter double bore tunnel plus the length of three deep stations makes up the 3.8km long central section. The tunnel itself is driven close to, and at one point underneath, the brick and timber buildings of the 16th to 18th centuries, all founded on ancient timber piles through soft, difficult and, above all, waterlogged peaty ground. All have suffered movement over the ages and are sensitive. Even outside the historic centre itself there are further pile-founded buildings from the end of the Second World War and equally vulnerable.

Most of the route is parallel twin bores at depth of 18-20m for the tunnel axis in between stations and rising slightly at the stations. For the narrow Ceintuurbaan station it is necessary to bring the tracks in one above the other and the western side tunnel swoops away from the other and goes deeper therefore to about 25m, passing underneath some buildings on its alignment. This is usually forbidden in the Netherlands and required special legislative dispensation.

It was felt that modern TBM methodology could make the drives but it was necessary to develop new levels of tunnelling control and understanding of building foundation behaviour says Frank Kaalberg. He is design team leader for the bored tunnels, from consultant Witteween + Bos which is part of the client's project engineer, joint venture Tunnel Enginering Consultants. Royal Haskoning forms the other half of the JV.

His team's work, over nearly two decades has involved both substantial research on the behaviour of the city's piles, a major survey of the buildings along the alignment, complex 4D finite elements analysis and development of a new level of real-time settlement monitoring above ground. The latter interacts with on-board TBM control systems to give much more precise control of excavation, ring installation and grouting. The whole has been christened the 'Integrated Boring Control System' or IBCS.

The first task was to analyse what alignments were possible. "The problem is both to avoid the piles in the ground and to avoid disrupting their bearing mechanism" says Frank Kaalberg. "There are thousands of timber piles usually driven into the dense 'first sand layer' about 12 to 14m down. They have some skin friction but also end bearing from a compacted cone formed around the pile tip. You have to avoid straight settlement and stress relief effects on this compacted material."

Conventional advice mostly suggested a machine would have to stay at least two diameters away, based on estimated volume losses on the tunnel line of one per cent to three per cent, causing settlement of 100mm or more above.

"But that would mean staying clear of buildings and driving very deep, which added costs at stations and means deep passenger access is needed," says Kaalberg. "You can route down the streets but they are narrow and anyway even they have pile supports for services and sewer lines."

He believed volume loss could be much less, but there was little published information on that or on timber pile behaviour in the Netherlands. In the 1990s his firm did a series of tests with specially installed piles at the second Heinenoort tunnel, one of the first bored tunnels in this waterlogged country. Using careful control of TBM grout injection it showed losses could be kept to 0.5 per cent. A half diameter was possible, and a distance of half a diameter between the two bores.

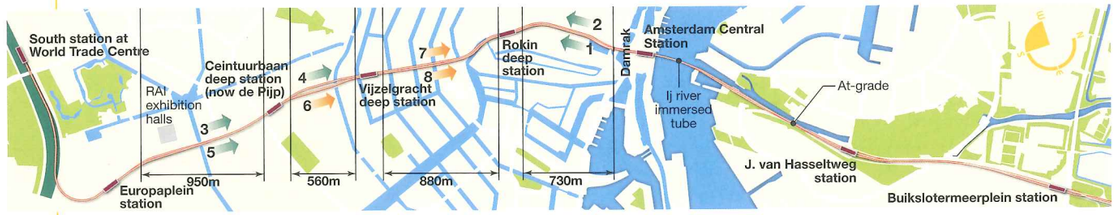
The results meant that a shallower, economic alignment could be used. Even so special measures were needed. First was to examine all the buildings in the city and assess their condition. Even though historic building regulations stipulate foundations be kept in good condition, many were unsound, "around 25 per cent," says Kaalberg.

A major survey and finite element analysis of building response was used to classify buildings at risk and notify owners. A 30 per cent subsidy from the city and insurance requirements then stimulated owners to make remedies with 98 per cent of buildings brought to a stable condition.

Monitoring

Meanwhile a complex monitoring system was devised using multiple robotic total stations set at key points along the alignment. Each takes round the clock

A view down the bored running tunnels that cut deep beneath central Amsterdan



Above: **Figure 1, the alignment of the tunnel showing the TBM drives along the route**

readings from prism reflectors mounted at three levels on all the building façades, more than 5,500 in all. Readings feed into a massive GIS database with hourly observations, which can track the settlement wave caused by TBM progress.

The original system has been upgraded with the advent of modern laser-based total stations which do not require prisms for accurate readings. These now supplement the building readings with distance reflections direct from the road surface, which means settlement effects can be detected earlier and more directly. Total station points have two instruments in the zone of TBM operations, the laser based ones moved along from point to point with the tunnelling.

The output from this system feeds into the operation of the TBMs below and is one factor in controlling settlement.

TBM design

First however was a special design for the 6.8m diameter Mixshields, devised in conjunction with maker Herrenknecht. The overarching principle was to shorten the length of the TBM head as much as possible explains Joost Joustra, the tunnelling project engineer for the Amsterdam City client.

"The shorter the machine head, the better you can get around curves with minimal ground displacement, which is always a significant factor affecting settlement" says Joustra. Measures include a 'bubble' chamber with its entry airlock extended into the chamber, rather than sitting behind it further along the machine. The compressed air bubble used to maintain the slurry pressure in the face chamber therefore surrounds the airlock.

Unusual three section telescoping hydraulic rams were also fitted to the machine for its push forwards from the segment ring, shortening them and their mounting points.

The shortened shield also articulates at the 55 per cent point along its length to further tighten turning capacity, helping it achieve bends in the alignment down to a 140m radius.

"That is encountered at around the point of the Royal Palace," says Joustra, "where the street pattern changes and there are turns nearly as tight."

"The machine is also rather specialised at the front" adds Frank Kaalberg "because it has a very open face with large apertures to cope with the soft ground and clay."

It would have been even more open he says but for the need also to carry disc cutters. These are required because the TBMs have to bore through the up to 1.5m thickness of concrete of the deep station diaphragm walls, which is obviously hard. "And because of the delays on the project it has hardened even more than expected," Kaalberg explains.

Shafts and compensation grouting

Aside from the main TBM tunnel construction, the North-South project also requires a variety of shafts and connections for both safety and construction purposes.

"The line has several cross passages between the running tunnels," says Amsterdam city engineer Remco E Kleinlugtenbelt. One of these is in the first drive from the Central station and two more in the second connection between the Rokin Station and Vijzelgracht. The 2.5m square section tunnels are being made by ground freezing to excavate between the lines which are just 4m apart. The point of excavation is fitted with special segments with a steel surround.

Passengers will use the connections as escape routes in the event of emergency.

"However, when the lines twist to run one above the other for Ceintuurbaan station it is not possible to use cross passages," says Kleinlugtenbelt, "because it would be psychologically disturbing to go up or down a steep incline." Instead escape shafts are provided.

Two of these are needed, the deepest to 36m down. They have been built by UK contractor Gallagher using a jacked, precast segmental technique, with a sharp steel penetration ring on the leading edge and a cast concrete reaction ring at the top of the shaft. The excavations to 40m for the deepest were done underwater, before plugging the base with a 2m concrete layer and dewatering. Connections to the tunnel again using ground freezing methods.

After lining of the 7m diameter shafts a 6m diameter space is left for stairs and emergency equipment.

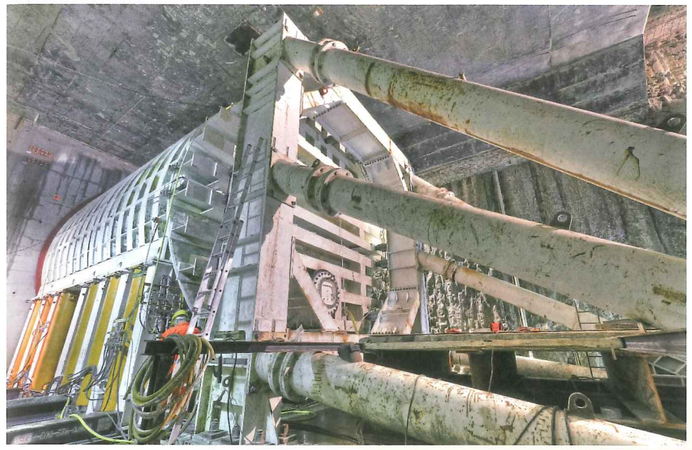
Gallagher's work has also taken in another seven smaller diameter shafts. These 5.2m diameter shafts are being used as key points on the project for compensation grouting underneath critical or historic structures such as the 1620 Munt Turm, a clock tower on the medieval city's Mint building.

The shafts are used to extend fans of tube manchette grouting pipes underneath the critical structures.

Techniques for grouting have been refined for the project including use of a two layer system, with an upper fan of permeation grouting done first to stiffen the soft ground and then compensation grouting lower down to compensate for the settlement as the TBM drives pass.

Most complex of the work has been 'Bridge 404', a historical bridge founded on piled brick abutments. The driven wooden piles are 13m deep. In this particular location south of the Ceintuurbaan station the tunnels are at different depths, the first passing 12m below these foundations but the second just 1.5m below the pile toes.

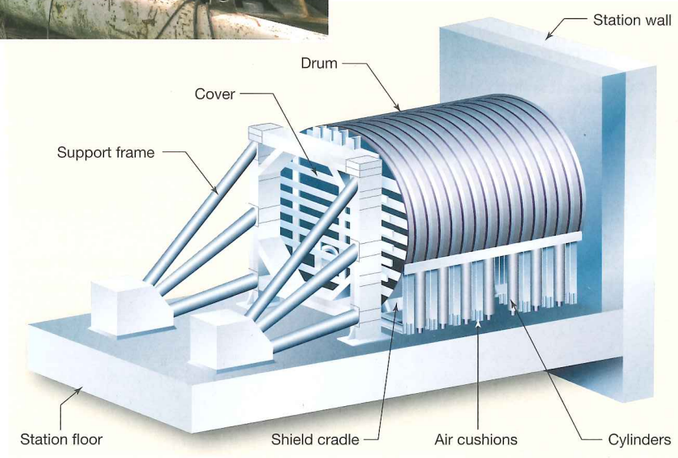
Both drives have gone well.



passed under the water-filled basin of the wet Damrak, where the tourist boats leave. The alignment began at a relatively shallow depth and headed a bit deeper while curving towards the main street.

After discussions with the contractor is was decided to do this work underneath overlapping ground freeze umbrellas about 2-3m thick over the two bores for the first 85m. "That gave additional security and prevented the possibility of a blowout early on" says Kaalberg. Once through, the section the 750m long drives went well, and

Left: **The TBM breaks through into the Sheild Transfer System;** Below: **Figure 1, Shield Transfer System diagram**



Transfer chamber

The shorter machine also aided design of another special feature, a transfer chamber made for the transition through the deep stations. The original sequence for the TBM drives involved two machines driving from the start chamber in a big caisson in the Damrak in front of the Central Station. From here the machines would arrive at the first deep station at the Rokin, pass through and move to the other end before recommencing the drive, passing in turn through the other two deep stations.

Entering the station means coping with the groundwater pressure at machine depth as the TBM's pressurised slurry-filled cutterhead breaks through. "Normally you would use a concrete block in the ground outside the diaphragm wall to make a seal but that requires a steel retaining wall to excavate inside to make it, which is difficult in such deep ground" says Kaalberg.

"You could use a diaphragm wall but that needs a lot of space and a grouted block is difficult too."

The solution devised is a pressurised steel chamber, held with steel reaction struts and sealed against the inner side of the diaphragm wall. It is filled with water at the same pressure as the tunnel face.

"As it cuts through the machine enters this 'Shield Transfer System' (STS) and displaces the water," explains Kaalberg. It continues making segment rings up to and in the diaphragm wall, grouted as usual and then additionally sealed. That done the STS can be de-pressurised and drained.

"It then 'walks' forwards on a series of vertical jacks," says Kaalberg. This copes with a second problem which is a deep point in concrete floor at the station ends where the base of future escalators will be accommodated. "Further on the floor is higher because we did not want to excavate any more than necessary, particularly to save on air pressure."

After 'caterpillaring' to the end, the chamber is again sealed against the wall for the tunnel exit. The TBM erects temporary steel segments within the chamber as it does so, the first with a bulkhead seal for the annulus which contains the pressure. That leaves the temporary tunnel interior open for the back-up train supplying normal concrete segments as the shield end reaches the diaphragm wall.

The STS has not been used as much as supposed however because the TBM drives were rescheduled to cope with delays at the deep stations, most of all the middle Vijzelgracht station which was not ready for arrival of the machines.

"The first drives began from the start-chamber at central station in spring 2010 with the second in August," says Joustra.

These had a complex start as they the settlements were well within the tolerances. "Up to 25mm is allowable but although it was around 20mm at the beginning, mostly it has been less than 10mm and even approaching zero," says Joustra.

"It took a while to learn the system," says Wolf Friedemann, project manager for the TBM tunnel contractor Saturn, which is a joint venture of Germany's Zublin and Dutch firm Dura Vermeer. "You have to take great care with the grouting and make sure that you inject 6.5m³ to fill the 6m³ space in the annulus. I was a little nervous about it at the beginning."

The TBM operator has information to monitor from pressure detectors in the tailskin and from the ITBS above ground he says. "The pressures change all the time so he has to be vigilant."

But his work team of mainly German tunnellers has got the procedures down to a fine art he says and on the next drives high speeds have been achieved.

Segment design

A walk along the TBM driven tunnel sections formed to date, shows an exceptionally dry and clean looking tunnel. One reason is the contractor's skill in following the exacting grouting and TBM drive procedures. But another is possibly an innovative segment design.

The ring system uses a newly developed resin sealed cam and pocket system to form a joint between adjacent rings. According to its designer Frank Kaalberg at Witteveen+Bos, the rationale of the system is to give the contractor flexibility in installation while stiffening the lining once it is in place.

Kaalberg explains that segment to segment joints within a ring are relatively weak and subject to opening under ovalisation deformities caused by soil stresses. Bolting holds them during erection but only temporarily.

One solution is to make stronger links from ring to ring to transfer forces back and forth. Friction joints - usually hardboard plates – can work but axial relaxation over time can reduce their effect or the plates deteriorate.

Cam and pocket systems in the segments can work but also have problems. They cannot be too precise a fit because that would limit erection flexibility for the contractor. So the cam is usually 5 to 10mm smaller, loose within the pocket. But then it only takes up loads as the ring deforms, perhaps to the point where a ring is effectively uncoupled. That creates uncertainty for the designer says Kaalberg.

For Amsterdam his team has devised a grout injection system in the connectors, to allow for the rings to be 'fixed' once they have been installed.

"But injecting the pocket directly is difficult," says Kaalberg. The team has devised small plastic inflatable 'cushions' therefore which are positioned on the delivered segments on indentations, formed on the segment during casting. They sit within the segment pocket, one either side of the cam's final position linked by a tube and another connects to the outside through which these are filled with a two component resin mix.

"The injection material is not as rigid as grout which is important for the way loads are taken up," says Kaalberg. Because of the inflatable cushions they are also able to take up whatever space has been left around the cam by shifts within the pocket.

The injection process has the further advantage that it can be done "at leisure" after the TBM has passed, as long as the tunnel has not undergone its relaxation process in the ground, in other words over several months. "We shall really know if it works in fifty years time" says Joustra.

These drives however have been made from the other end of the alignment because the ordering of the drives was changed to cope with delays and difficulties on the deep stations.

"Work at Ceintuurbaan, expected to be the last to finish, went better than the rest and so it was decided to do the rest from the south," explains Joustra. The first TBM shields would be sacrificed, and all the equipment transferred to the southern end of the line.

"This was possible because an initial cut and cover section of the line which starts it from the surface south of the main exhibition centre, had been completed" he says. That gave relatively easy access; earlier a southern start was ruled out because it needed shaft works, disrupting Amsterdam's important international exhibitions business.

To make the change, new TBM shields were ordered and the important equipment and motors inside the first shields were stripped out to rebuild the TBMs. The bentonite plant, grout plant segment supply system and spoil disposal systems were also moved.

"Fortunately," says Joustra "there was a disused area close to the Amstel river, which local residents suggested. It is close to the city ring motorway and has access to barge loading for spoil." A new pipeline runs there. The material cleaned from the bentonite is carried to a section of the old deep harbour which is being partially filled to create shallow water for development.

The two new machines are now driving north, first making the 950m bore to the Ceintuurbaan, before begin transferred through with the STS and then onwards.

"Because of the extended completion time the drives are made one at a time, with one set of shift workers operating each TBM in turn," says Joustra.

Drives for the western side were begun in May 2011 and made through Ceintuurbaan to the Vijzelgracht station where the TBM has been 'parked'. Meanwhile the other side began in December last year and completed as far as Ceintuurbaan by Easter. The sixth eastern side drive was underway in early summer and the crews were due to switch sides again for the final western drive after that and the final, eighth drive, to complete early next year.

Below: The Zublin Dura Vermeer team poses in front of the TBM

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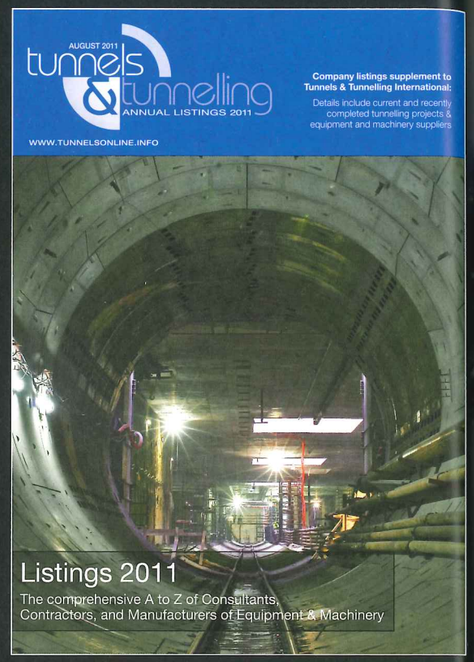

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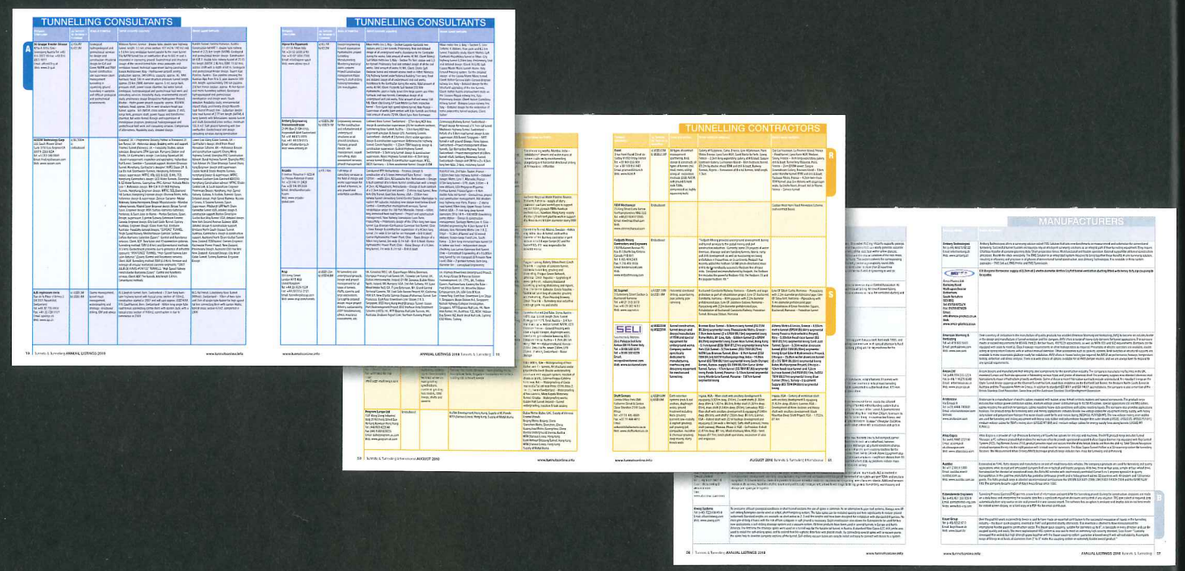

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A section of the immersed tube tunnel is tugged along the river Ij

The river crossing

At the northern end of the project an immersed tube continues the underground line beneath the Central station and across the river Ij. technical journalist Adrian Greeman reports from site

In early planning for the North-South line is was thought that bored tunnel could continue the route into North Amsterdam, an outlying part of the city across the main river around the city, the Ij. But that meant passing with TBMs under the historic late nineteenth century Amsterdam Central station, a centrepiece of the city known to millions of tourists.

"At that stage we still had no bored tunnels in the Netherlands and it was thought obtaining permits for the work would be extremely difficult," says Frank Kaalberg at the project's lead consultant Witteween+Bos.

Abandoning the link and ending the route at the Central Station would have been impossible; providing a connection to a part of the city that often feels cut off and abandoned was politically crucial. The suburb has a free ferry foot passenger and bicycle service across the river, granted some decades ago by the city 'in perpetuity', but is otherwise difficult to reach except by a long road route around. New development and housing there makes the connection now even more important.

The Dutch however are very skilled at immersed tube technology and so it was decided to make the crossing this way. "It could also be shallower with this method" says Kaalberg "because a bored tunnel would have to pass at least 6m below the piles of the Central Station."

The station

The station still had to be passed and the method for doing so has been one of the most complex and difficult parts of the whole project. It has been done with an extension of the immersed river tube effectively, a special element floated into a water filled cavity built beneath the station and then backfilled. The float-in operation was completed at the end of 2011.

Creating the space for the tunnel element using a vast underpinning operation and then building a huge table-like structure beneath the station with jet grouting piles and vertical microtunnelling, has been a gigantic operation in itself. Staggering ground engineering challenges have been met, not least in supporting a listed historic structure without damage, and removing thousands of ancient timber piles to make a space for the new tunnel box (see detailed story *T&TI* October 2011, page 30).

Since that element was installed, work has proceeded quickly on complex in situ concrete work site in a riverside cofferdam work just outside the station. This will make up a station concourse and passenger links to the main station, and will provide the southern abutment for the immersed tube.

Caisson erection outside Amsterdam Central station

The crossing

It comprises a three element connection from the Central station to the north river bank. Here there is an abutment with an in situ concrete tunnel section, currently under construction, which lifts the line up to surface level. The line runs on at grade once it is into the northern district.

The immersed tube section, being carried out this year, is relatively straightforward compared to many other large and deep immersions worldwide, says Maurice Reijm, senior project engineer for contractor Strukton. The specialist marine works firm is working on the immersion in joint venture with dredging specialist Van Oord. Together they are both subcontracted to Zink which has the overall river connection works. Zink is a consortium of Heijmans and Strukton.

"Dredging for the tunnel channel and preparing the site for the immersion operation already began in February" says Reijm. The tunnel is due to floated into position in autumn this year, one element each week from 25 September.

The long coffer dammed construction pit for the in situ work on the north side was built initially as a construction dock for the immersion elements. These were concreted and completed some time back between 2005 and 2007 and have been stored ever since in a part of Amsterdam's harbour around 12km away. Once monthly inspections ensure that they remain in condition and that interior humidity does not cause any problems for the tanks and pipework inside.

The roughly 450m long construction pit was created from an old yacht marina on the north bank of the river and was used to make the elements two at a time. The contractor Zink built the under station element there as well as the three units required for the river crossing.

The station installation was done by a different consortium but it made obvious sense to use the dock facility for all four elements, especially as Strukton is involved in both jobs.

Tunnel elements are roughly the same size, 8m deep, 140m long and 12m wide to carry twin lines for the railway. The station element is wider because it will be part of the Central Station with connections to the main line railways. It has side platforms for the passengers and walkways to the concourse areas at either end.

But the other units are also unique, each with its own geometry because of a curve on the cross river link.

"The connection is also rising as it comes across the river and so each element changes in both plan and vertical alignment" says Reijm.

Setting up and checking the formwork for concreting these 'bananas' was one of the challenges at that stage he says.

It also created some extra issues when the units were floated and then moved to the holding mooring 12km away at Suez Haven. Because of the strange shape he says, the units have a tendency to deviate slightly in the water and need constant correction by the tugboats.

This will be part of the challenge in the autumn when they are brought from the Suez. It means ensuring a five tug configuration with four on pulling ropes to adjust the course and one pusher tug.

By then the river trench and two steel

Right: **Working within the caissons, water jets and pumps remove the clay**

Caissons

One other form of tunnel construction completes the underground alignment towards the north end of the line – caissons. These provide a link section between the immersed tubes of the river and Central Station section, and the start of the TBM drives south.

The caissons begin by an in situ concrete excavation within diaphragm walls just outside the Central Station, on the big 'Voorplein'. This concrete complex is the southern concourse of the new North-South line Central Station. It provides stairways and escalators to the main railway station above and to the east-way subway line.

Then come three caissons in a row. First is a small one 26m long, 11m deep and 13m wide, big enough for the twin tracks of the line. Next is similar but 42m long, and then comes a much larger structure 60m long. This is deeper at 20m, because the line runs on a steep gradient through it into the bored running tunnels at a lower level. It also widens outwards from the 13m width to 20m at the far end where the two bored running tunnels are launched.

The reason for using caissons is to get through an area of water in front of the station, part a channel of the river Ij created when the artificial island for the station was built at the end of the 19th century. At right angles to that there is also a waterway beside the Damrak, the broad road known to all tourists which runs from the central station to the Dam square. The Dutch call this inlet the Natte or wet Damrak, known to all because it is the mooring point for all the canal tour boats .

"It is a fairly important location therefore and a channel had to be kept free during the work," says Frank Kaalberg, design project manager for consultant Witteveen+Bos. "But the site is the right point for the TBM drives and well located for water transport of materials and equipment."

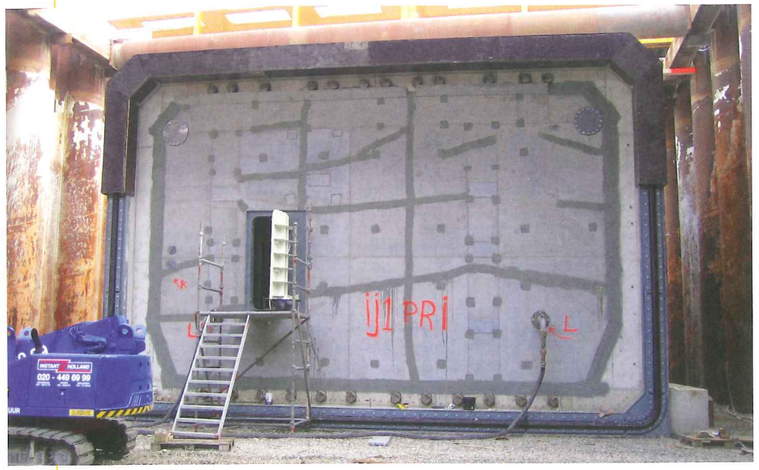
The three caissons are constructed within a coffer-dammed area, which will be flooded again once they have been sunk to their final depth, the box tops some 10m below ground. Sheet pile shafts on top will give access.

The smallest unit and the big one were both built early on, in 2005-6, the small to make an end for the forecourt station work and the larger because it served as the launching chamber for the first TBM drives. Contractor Heijmans, which is doing the three units, began construction on the third middle caisson at the end of 2011 and had finished most of the concreting by March this year. Caisson sinking began in May.

Sinking the the huge units demands excavation of the soft clays and peat beneath, which is done under compressed air working says Valesca van den Boogerd, project engineer with Amsterdam City on this section of the work. "They have to use up to three atmospheres of over pressure which limits working times to around four hours," she explains to *T&TI*.

Excavation is by pressurised water jet on the soft ground which is then pumped out to barges. These are bottom emptying units which travel to a marine spoil disposal area on a part of Amsterdam harbour which is currently being rebuilt with shallower water depths.

Once at full depth the caissons need to be stitched together and fitout work completed inside. An important feature, apart from tracks and other work, is installation of big radial steel gates in the largest caisson; these are the emergency stopgates if the tunnels should be breached at any time or there is a 100 year storm event.



Above: The banana shaped segments will be floated, sunk and sealed this autumn

sheet pile cofferdams will have long been installed and prepared. The cofferdams at either end help reduce the dredging required by allowing a 19m deep trench to be formed without a long shallow batter either side.

"We will also have placed six foundation pads, two for each unit, where the secondary end of the element will rest on steel pins through the tunnel floor," says Reijm. The precast pads are being made currently and comprise a tapered concrete block with a steel plate on the top.

The tunnel units will be brought into position with the secondary end as the 'bow' during transport.

That protects the delicate rubber Gina gasket which is on the primary end of the unit, to seal it against the steel frame of the abutment or the next unit.

"That means they have to be manoeuvred around and the pusher tug moves to the other end" he says. The unit will then be eased as far as it can into the 80m long coffer dam with the tugs at first and then by hauling inwards with a winched cable connection.

Positioning

Once inside, the element will be connected to two big shear leg floating cranes, with a three point configuration for the cables.

"These will be the main adjustment for the elements as they are then ballasted and sunk" explains Reijm. Unlike most immersion operations he says, side to side and tilt adjustment cannot be done by altering the distribution of the ballast water in the tanks inside the elements.

"The elements are pretty narrow and therefore the ballast tanks have to go right across the width inside." End to end orientation will still be possible however.

The units will also use an innovative survey system from Geocon for the immersion itself, the so-called taut wire measurement developed for the Korean crossing. This replaces the usual survey tower system, which uses a frame mounted on the unit keeping a survey point visible above water for positioning by total station observation.

"Taut wire is exactly as described," says Reijm, "a wire kept at constant tension by a hydraulic roller system. Distance and angles on the wire, in plan and vertically, can be measured to determine the element's position. "It is very accurate."

Underwater, positioning and connection will be done by traditional means says Reijm, though with an innovation there too. That means use of primary beams on the gasket ends which rest on the abutment or the previous section, where there are catches installed.

Jacks inside the hollow beams will pull the Gina gasket tight against the steel facing plate before the joint area is pumped out and water pressure pushes the seal even tighter.

Unlike normal primary end beams however these will also have vertical jacks installed. It means the beams can be raised and lowered to adjust the element position. "And by using the jacks in the opposite direction on the two beams it is possible to slightly alter the orientation of the element," says Reijm.

The combined system, which eliminates the need for a separate vertical adjustment mechanism, was developed for work on a crossing in Limerick in Ireland, he says.

At the secondary end, meanwhile, the pins will rest on the steel foundation plates leaving the bottom of the element 500mm clear of the trench floor. In the under space a sand filling is pump installed via tube connections to a hollow lip around the concrete base of the units.

Connections are made every 10m along, placing the sand in 'pancakes' as they build up underneath and gradually fuse together. Load reduction on the vertical primary beam jacks and the secondary pins, are used to measure the back pressure from the sand to indicate when the foundation has completed.

"Then the secondary pins are withdrawn," says Reijm.

Each unit has a 24 hour window for this placing operation, one a week into October, when the river traffic on the busy waterway will be stopped completely.

For the third and final unit there is additional work.

Like the first it will be winched into a cofferdam area. But it is installed in the opposite direction, with its Gina gasket against the far abutment. That leaves a space between its secondary end and the secondary end of the middle unit. This closure joint, 1.5m long, has to be sealed with steel formwork panels placed by divers.

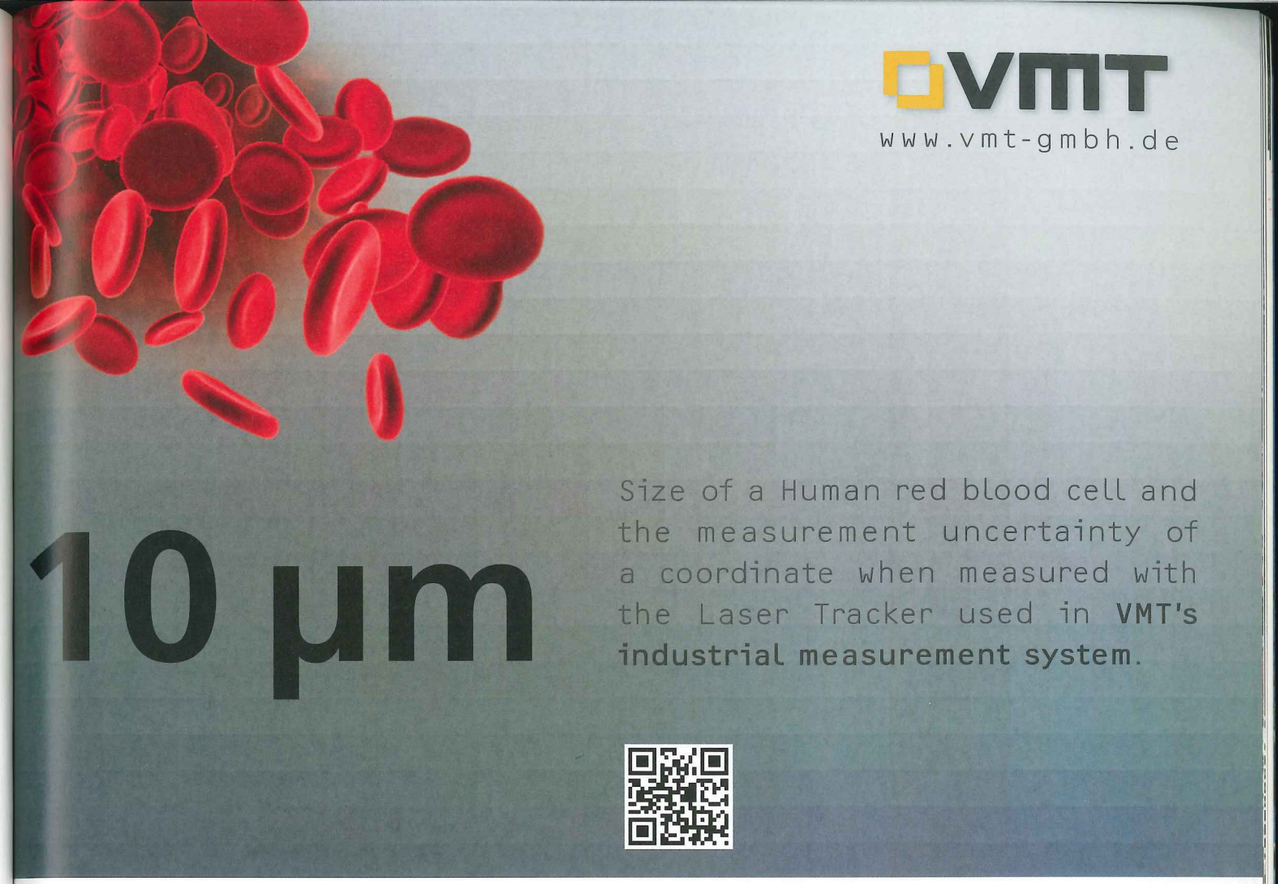
"The shear legs will lower down formwork panels and then we can pump out the water from the sealed area," explains Reijm.

Operations in the days after each float will continue with a gravel locking fill placed around the element and then a timber and rock armour above to complete the backfill. "That protects against dragging anchors and the like" he says.

Barring unlikely earthquakes, or hurricane winds which are equally unlikely in the quiet early autumn, things should then be complete outside, leaving the internal work to be done inside the tunnel.

An important job is cutting the post-tensioning which keeps the elements stiff during the float-operation. Each element has six segments with concrete construction joints between them which allow some flexibility to accommodate differential settlements.

The temporary concrete bulkheads will also be removed and the immersion equipment and ballast tanks stripped out. Concrete bases will need casting to provide a track bed and adding weight to reduce buoyancy. Then it will be handed over to the track work and signally teams.



The work site in front of Amsterdam Central Station

Station stops

In the centre of the old city, the stations have been the most obvious part of the new construction – as well as the most difficult and time consuming. Subsidence troubles on the second one almost ended the project in 2009. Technical journalist Adrian Greeman visits the stations

The three stations along the central underground section of the line, Rokin, Vijzelgracht and Ceintuurbaan, have all been a major challenge to construct, each within a huge underground box of diaphragm walls and concrete floors. They are on the critical path for the work and delays here have been the main factor in stretching out the project schedule.

Firstly they must be built up to 32m below ground, which is no easy matter in the waterlogged soft soils of the city and with the high water pressures that implies. It affects both the design and the construction work.

Secondly all the excavation and construction must be done in some of the busiest streets of the historic centre, close alongside ancient buildings and their pile foundations and with traffic, trams, tourists and residents passing above and alongside. Noise and working time limits are tight, space constrained, and equipment restricted.

The three stations all have their own characteristics. First is the Rokin, the most central and close the main Dam square and the palace. It sits halfway along the Rokin which is a historic street, once the course of the river Amstel and then infilled when the Dam was built some centuries ago. It is now on one of the rings in old Amsterdam's wheel-and-spoke street and canal layout.

Its wide dimensions allows for the easiest of the three station structures since the station has relative space to spread out. That means it is wider than the others at 33m and can be kept shallower, going only 27m down. It is 250m long.

On the edge of the old centre but still alongside historic houses, perhaps unfortunately, is Vijzelgracht. There is less room here but it can still be 20m wide, this time dropping to 30m deep. It is here that problems were encountered with the diaphragm wall joints, leading to an inflow and building settlement.

Further south Ceintuurbaan is located in a narrow street in a newer part of the town, built just post-WW2 and near to a well-known street market which is one of the city's tourist attractions.

Space limits between the buildings mean the finished station here is 11m wide, just under 13m during excavation. To fit the line in, the tracks have to be stacked one over the other instead of side by side. The box is therefore deeper at 31m, if not much more than Vijzelgracht. Full excavation depth reached 33m.

A confident strut

Like all the stations, the buildings around are on relatively shallow piled foundations through the soft peaty ground into the first sand layer, though rather then the timber piles found on the older buildings, the post-war foundations are mostly steel. "But they are often not that sound and close to a safety factor of one," says Henk de Pater, the city client's project manager for the station. The design for each station is similar, a perimeter diaphragm wall of 1.5m thickness and dropping as deep as 47m for Ceintuurbaan, reaching the impermeable clay which sits above the deepest 'third sand layer'. It has to resist high water pressures in particularly the various sand layers encountered, which means it reaches a maximum of 3.5 bar.

Because of these high pressures, project main designer Witteveen+Bos added a jet grout 'strut' at the base of the diaphragm walls on each station to supplement the normal steel struts and concrete floors installed higher up, which usually prevent deformation of the walls.

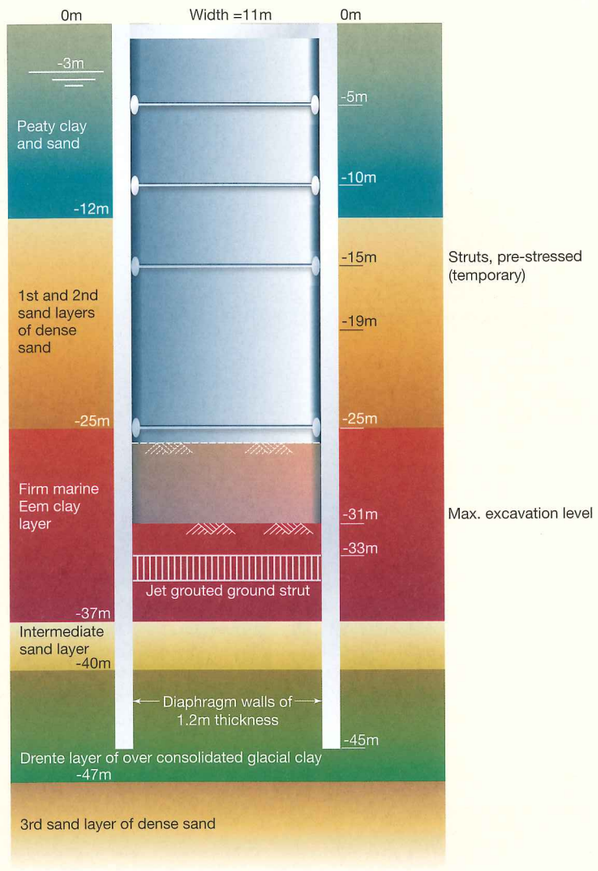
The designer believed that the position of walls close to buildings just 3m away, and the depth of excavation well below the bottom of the house piles, which are just 13m long, made the addition important (see diagram, page 54).

The jet grout columns are in contact but are specifically meant not to overlap completely such that they form a floor adds Witteveen+Bos design engineer Richard de Nijs. "The water is supposed to come through," he adds.

Installation was done using an observational method with modifications to the installed pattern made as measurements were taken, and core samples retrieved during the subcontractor's work. This took around five months at Ceintuurbaan and similar times at the other stations. The aim was to achieve a stiffness between fairly tight limits 1000MPa and 2200MPa, which was done.

Sinking the walls

Ground strutting work came at the end of the diaphragm wall installation at the



Above: **Figure 1, the stations were constructed using the top down method**

stations, which was mostly carried out by Belgian firm Franki working for the German main contractor Max Bogl which did all three stations. Work began in 2003.

Installing the diaphragm walls took longer than supposed initially, particularly because of the working constraints at the site which allowed only a limited number of the big diaphragm rigs to work at any one time. This was especially true at Ceintuurbaan where an initial site occupation layout, taking up most of the street, had to be abandoned because of traffic and pedestrian problems. A method of working one side of the street and then the other, leaving access to local shops, was found.

"Here at Ceintuurbaan it took us three and a half years or so to do the walls," says de Pater. "It had been estimated by the city that it could be under two years" he says "but it was realistic to believe it would be longer. It is very difficult working in this very wet and soft ground to achieve verticality."

One problem is local vibration in the soft peat layers at the top he says. "You can feel when heavy machines or trucks pass by and there is some movement between the wall panels."

Walls were built conventionally with a small concrete guidance wall set up at ground level and using a grab system.

Once in place the station top could be formed. For the very wide Rokin station this was done with precast units laid out and then stitched with in situ concrete. The beams rest on internal columns halfway across. For the other stations a top slab was cast. At each station excavation then was carried out by top down construction, using three apertures in the slab for mucking out.

Spoil was lifted out by crane in 8m³ skips which load in threes onto trucks to run out through the narrow city streets. There are various options for the disposal. Top and potentially contaminated layers go to disposal sites, but lower material can be used for harbour infill and in the case of the dense clean sand layers, makes an excellent raw material for building work.

"Mucking out has been quite a constraint on the contractors," says Pelle de Wit, Amsterdam City assistant project manager at the Vijzelgracht station. "Inside the station particularly, logistics are quite difficult as there is considerable strutting which has to be worked around for excavation and then concreting work later."

Most stations are strutted at 6m intervals with largescale temporary steel tubing. Further down a permanent concrete slab is made which becomes the eventual station roof for the train platforms that are at the bottom of the station box.

"The space above, over four floors, will be used for car parking" says de Wit. At Rokin this will comprise four floors of concrete underground parking space, the floors of which will provide permanent strutting. At Vijzelgracht the space above will "probably have parking using an underground robotic system to store the cars in steel racks," he says.

Under pressure

The initial concrete slab roughly 19m deep at the bottom has a secondary purpose, namely for containing compressed air. The depth of the stations and the permeability of the sand layers meant that uplift from ground water pressure needed to be contained by working under air once a depth of 25m is reached. Up to 1.9 bar overpressure was used in the case of Ceintuurbaan and just under one atmosphere at Vijzelgracht. At this lower pressure the health and safety issues are much reduced and shift times can be close to normal.

"For design the air pressure loads are the main loading factor to consider in the specification of the slabs" says project engineer Richard de Nijs, at consultant Witteveen+Bos.

It was originally supposed that some compressed air work would be needed at the less deep Rokin station too but calculations by the consultant showed that friction from the diaphragm walls could play a significant part in restraining uplift. As its depth was less, the work could be done without the air. It also helped that the station did not have an 'intermediate' sand layer with water under pressure.

Jacking building

One element in restoring public confidence in the North-South project has been restoration work on the four 1780s Weavers Houses damaged by settlement, which has been the most public aspect of the engineering difficulties.

The operation, developed by a small team at Witteveen+Bos, used a multi-jack method developed for bridge installation, to push the building floor slab back into position and re-activate piles or in a few cases install new ones. It required complex analysis to adapt the jacking system for a special purpose.

The challenge for the team was to apply this technique to a very uneven settlement. The method was developed for controlled jacking of pre-cast bridges onto their final abutment seatings and did not allow for much variation.

"The buildings dropped on one point by 230mm," explains ground engineer Richard de Nijs of the consultant. "But they tilted and slightly rotated during the incident in a complex deformation."

Complicating the pictures was the slow steady settlement of two and a half centuries which had left picturesque but distorted window frames and doors. Restoration would require asymmetric jacking to match the failure.

"It also had to be carefully controlled and paced to avoid causing additional cracking by uneven loading of the movement back," says de Nijs. Even some 16km of emergency timber propping inside could not be counted on to stop that.

"Fortunately the buildings were on modern steel pile and concrete slab floor foundations which had been installed in 2001, rather than the original timber wall piles," he says. "It could be assumed these were level at the time."

First task was to confirm the usability of the piles and then analyse the changes using movement records from the façade prisms of the tunnel monitoring system and the new floor positions, along with a finite elements analysis.

The restoration method involved excavating into the slab to find the pile caps and attaching hydraulic jacks to them. Each was instrumented and monitored for a complex hydraulic control system for the lift operation which would try to restore the original levels. "And there were all kinds of sensors on the building too," de Nijs says.

"A difficulty was that the contractor's system could only allow for the piles to be operated at different rates of jacking in sixteen groups," says his colleague on the work Sujeet Bhageloe. For bridges that was important to prevent cracking; here the opposite was needed because of the irregular deformities across 51 piles.

"We had to simplify the shape of the assumed deformation for jacking," Bhageloe says. In the event it proved possible even to remove some of the residual deformity – the dent in the foundations.

The USD 175,475 jacking operation lasted a nerve-racking three days last year but has successfully repositioned the buildings and reconnected its piles. Some careful repair work on the building superstructures, matching the original bricks and timber as far as possible has restored them almost as they were. Helping with this is the inherent flexibility of the old mortars which crack less easily than modern materials.

"The buildings have lost some of the weathering and ageing which is important for the city heritage, but at least have now been re-occupied and are in better condition than before," says de Nijs.

Right: **A sequence of leaks through the diaphragm walls of Vijzelgracht station caused major settlement on old buildings**

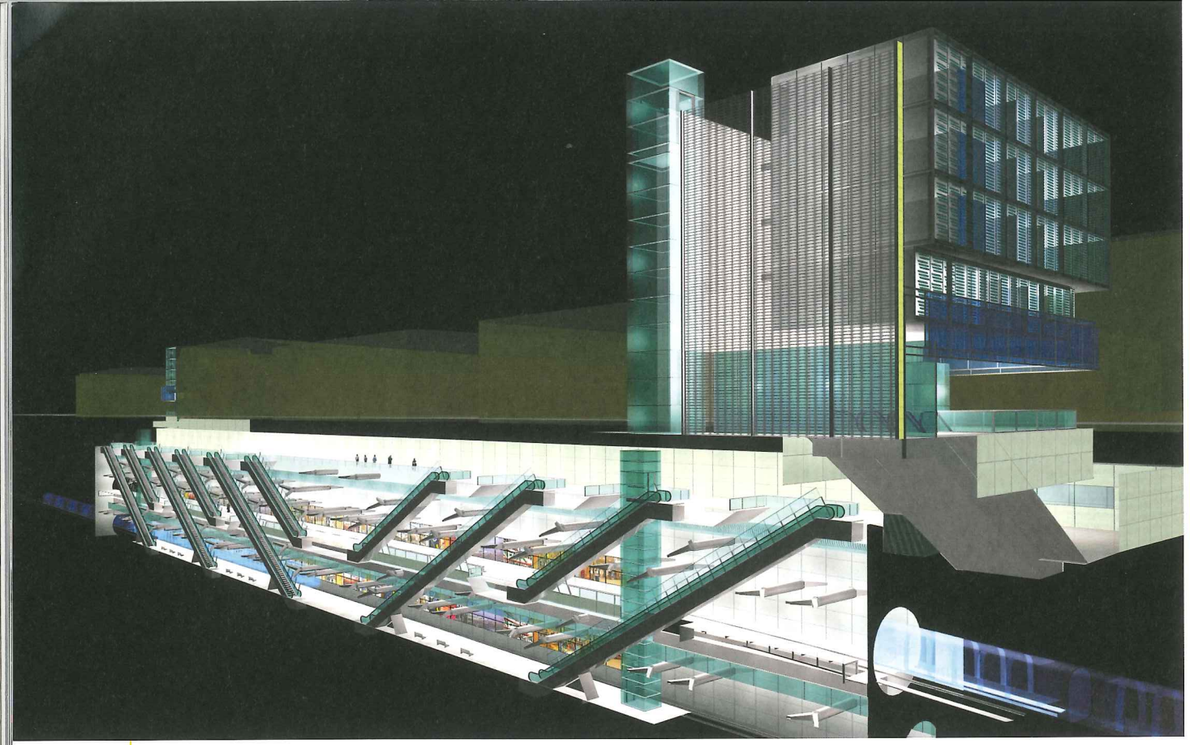
This extra sand layer is found at about 47m deep in some locations in the city sitting in between the main second and third layers. It was present at both the other two stations and for each a dewatering system was used to reduce the pressures from it with wells drilled down to around 45m below ground, just above the end of the diaphragm walls. An incoming water flow of about 5m³/hour had to be pumped at Ceintuurbaan, and nearly twice that at Vijzelgracht station.

Dewatering did not completely eliminate the need for compressed air working but it did reduce the incoming water pressures from below the station and allow for some reduction in the compressed air overpressures.

For a while it was thought the pumping and friction mechanisms would allow Vijzelgracht to eliminate compressed air working altogether. But after some dramatic incidents in 2008, when diaphragm wall leakage led to settlement of some historic buildings, this was not possible. The City wanted the most conservative way of working to be adopted and air overpressure was used for the deeper parts of the excavation to add a margin of certainty.

Pumping was also made more secure by installing vacuum pump technology on the well heads and making a duplicate set of wells, some forty in all, as a redundant backup system.

The settlements came early on in the excavation work when it had reached about 13m deep, roughly the level of the first sand layer and the end of the timber piles on the



Above: Figure 2, a 3D computer generated image of Ceintuurbaan Station

historic buildings.

Uncontrolled settlement

Two major events occurred which stopped the station work for over a year, and raised questions of cancelling the entire scheme. First was in June caused by leakage between two panels of the diaphragm wall, most likely because of a misplaced or damaged water stop though it has not been fully determined yet. A rubber stop seal is added during panel excavation which is held in place by a steel frame as the next panel is grabbed out and then removed before concreting. Taking it out can be tricky. Whatever the cause there was some water inflow.

"That was not good but the real problem was that the inflow brought ground material in with it," says de Nijs, "with a 15m head of water driving the erosion."

In a first small incident there was only 2mm of settlement but two days later a second leak caused a large volume of water entry, along with sand. The result was very rapid settlement propagated to the surface impacting on buildings close to the station works.

That was serious enough, causing subsidence at the surface of about 160mm underneath some 18th century houses. Fortunately the buildings though damaged were still usable says de Nijs.

"Work stopped and everyone sat down to consider the incident" says his colleague Sujeet Bhageboe. Over three months the joint could be repaired using resin injection and the diaphragm walls were inspected for further problems but although some 'sweating' was observed, it was nothing out of the ordinary.

It was agreed that work could continue but with a specified sequence for spoil removal and only one joint at a time. So in September excavation continued. Within two days there was another inflow, which was even larger causing a drop of 4m in the water table at the surface, and a total 230mm of settlement.

A row of historic Weavers Houses dating back to 1780 suffered major cracking and movements lasting four hours forcing evacuation of the occupants, mostly local businesses. Some 15km of timber shoring was used to prop up the structures in subsequent days and the city ordered a stop of works.

A year long hiatus followed while the cause was examined and investigated and the city decided on what to do.

The immediate difficulty was clear; there was a hole in the diaphragm joint several centimetres wide caused more likely by a bentonite inclusion. How that happened is again subject to varying opinions which may yet be contested legally.

But rather than attribute blame at the time, and potentially bankrupting various parties, the city decided to rebuild relationships, establishing new pain-gain partnering contracts and a new set of procedures for monitoring and organisation of the work. Disputes may yet be fought out but after completion.

A key element was how to monitor the diaphragm walls joints and how to remedy flaws. The solution eventually agreed was to use ground freezing to seal any possible leaks ahead of excavation.

The freezing would be internal rather than outside. External freezing would allow ground pressure to help seal the joint as an ice body built up. "But there would be a risk of ice buildup disrupting the ground structure" says de Nijs.

On the inside wall therefore, twin freezing pipes were set up by each joint, to form an ice body about 2m thick. Excavation could then proceed very carefully joint by joint, with the possibility of replacing spoil if any leaks were found.

"The ice body itself was carefully milled away using a roadheader attachment on an excavator " explains Felix Paleari, the city's project leader for Vijzelgracht. Since this also milled away the ice pipes during each 2m deep bench, they were reattached across the gap with flexible hoses.

Once exposed the joints were assessed and sealed with a low temperature setting grout mix. Steel plates were then fixed across the joint for sealing in one of five categories, of increasing heaviness. "There is a later concrete lining to go in which covers this and adds to the wall strength" says Paleari. With these methods the remaining excavations have been completed, the last at Vijzelgracht finishing in December last year. After installing the 2m thick base slab for the station the attention is now on building up the internal concrete structures and eventually fitting out for the stations, continuing until 2014.

Once the TBMs have passed through the stations to complete the main tunnels drives, track and signalling will begin too.

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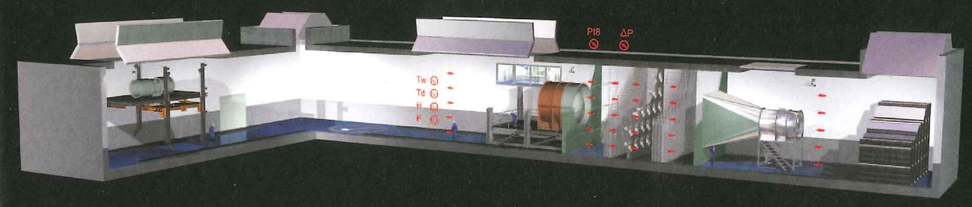

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An improved jet fan

This paper presented by Harald Rudelgass and Carlo Barbetta of Systemair explores the results of converging nozzles on loss of impulse, a history of the research and the latest solution

Road tunnels are often ventilated by inductive systems with booster fans, also known as jet fans, installed near the tunnel ceiling. A brief summary of physical data is necessary to better understand the scope of this paper.

The theoretical impulse force for a jet fan, thrust, can be calculated as follows:

$$(1)\quad T_f = pq_vV_f$$

In practice a jet fan experiences losses and so will not develop the full theoretical thrust force.

The actual thrust can only be found by measurement. Action and reaction are equal and opposite so the thrust provided to the air can be evaluated by measuring the reactive force on the fan, as specified in ISO 13350. The difference between theoretical and real thrust ranges from 0.85 to 1.05 (values greater than one happen in some cases where a high hub ratio generates a remarkable annulus velocity, affecting outlet velocity). The authors warn the user on calculating the thrust with the above formula. It is recommended to measure the thrust and then calculate the V_{eff} (effective velocity) from the appropriate formula [1].

Since the flow rate in the tunnel will not be zero, formula (1) must be rewritten in the following way :

$$(2)\quad T_f = pq_v(V_f - V_t)$$

Manipulating this formula

(multiplying by $\frac{T_f}{pq_vV_f}$)

and solving the equation for T_f we have:

$$(3)\quad T_f = \frac{T_t}{\left(1-\frac{V_t}{V_f}\right)}$$

In order to free as much of the tunnel for traffic as possible, booster fans are often installed close to the ceiling. This results in the exhaust jet stream not being able to fully develop. So a portion of jet energy is lost to wall friction. Consequently, formula (3) has to be rewritten as follows:

$$(4)\quad T_f = \frac{T_t}{k\left(1-\frac{V_t}{V_f}\right)}$$

The effectiveness number k, called the 'Kempf factor', indicates what portion of the impulse force or momentum is actually provided by the fan and not lost.

Generally we should assume:

V_f = 30m/s
V_t = 5m/s
And we immediately have a factor of

$$1-\frac{V_t}{V_f}$$

Studies, presented later in this paper, demonstrate that k can range between 0.65 to 0.78, resulting in a correction factor on the provided thrust of 0.54 to 0.64. This means a loss in thrust of 36 to 46 per cent. This is a remarkable amount of energy loss, and needs an appropriate focus.

Below: Testing a Mojet fan

Notation

T = force, thrust	(N)
p = fluid density	(kg/m³)
q_v = flow rate	(m³/s)
V = velocity	(m/s)
K = Kempf factor	(-)
θ = angle between jet stream and longitudinal tunnel axis	(°)
Z = distance between fan axis and tunnel roof	(m)

Subscript notation

eff = effective
f = fan
t = tunnel

History

During the mid 1960s a Swiss engineer, I Kempf, started to study the influence and effect of walls on jet streams [2] in a corner of rectangular tunnel section model. That was the first approach trying to determine the effects in an engineered way. Later in 1979 E. Rohne [3] resumed the previous work and began an analytical investigation of a simple jet on a plain plate. In 1982 Rohne [4] also studied the simple jet in a niche. And again in 1985 [5] and 1988 [6] Rohne studied the effect of two and four simple jets on a plain plate.

All Rohne experiments were purely a pipe or pipes positioned in the vicinity of a plain plate or plain niche, and not taking into account the shape of the tunnel at all. This research showed the great influence of losses generated through interaction between jet plumes and fixed surfaces.

In 1991 [7] the prolific Rohne presented research that in some ways reproduced, the circular shape of a tunnel: a half cylinder in small scale (maximum radius of 400mm and length 2,000mm), with one pipe positioned in the middle at various distances from vault.

The research carried out to this point had two technical limitations:

- Pipes do not correctly represent a jet fan outlet, which has a swirl.
- Plain plates or semicircular sections do not create boundary surface existing in a tunnel.

Also in 1991, N. Costeris [8] resumed the Kempf research for a rectangular tunnel presenting the dimensionless effectiveness of jets. Again the first technical limitation (above) was an issue.

For the first time graphs showing the k factors were of easy use and directly applicable to formula four (above, left).

The author suggested how to improve the results by using deflectors on air outlets, correcting the final thrust by the cosine of the angle between the jet stream centreline and the longitudinal tunnel axis.

Costeris's comments on use of deflectors are very clear, that the adoption of jet stream deflectors is only considered an improvement if the advantages outweigh the drawbacks caused by the additional losses through the jet fan, and consequently the increase of power consumption.

During the 1990s there was a big jump ahead in the research. The Department of Mechanical Engineering of the University of Padua in Italy and the Centre for Tunnel Aerodynamics Research at the South Bank University in London, UK worked together in a joint research program and improved the analysis of k factor.

The major improvements were:

- Creation of a scale model of a real tunnel cross section (ANAS 505, Italian Road Authority) at a scale of 1:10.
- Creation of a jet fan scale model 1:10 including the typical swirl angles, with and without silencers.
- Both single and pair jet fan scale models at various distances between the vault and fan centres. And also analysing effect of distance between jets or pairs.
- Benefit analysis of inclining the jet.

The work done was presented in 1994 [9], 1997 [10] [11], 2000 [12] and today represents the more updated Kempf factor determination.

Technical solution

From formula (4) it is clear that the Kempf factor is an extremely important influence on the number of jet fans to be used and consequently installation and running costs.

The data in [9], [10], [11] and [12] confirms that it could vary between 0.65 to 0.78 so any improvement achieved will give benefits as described above.

Jet fan inclination

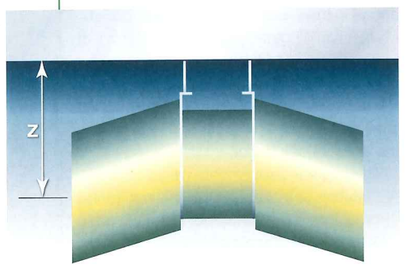
Fully reversible booster fans in a bidirectional traffic tunnel, or in a unidirectional tunnel that, during maintenance allows two way traffic and does not allow the adoption of inclination that will only benefit one direction. In some cases the inclination is not achievable due to tunnel clearance demands.

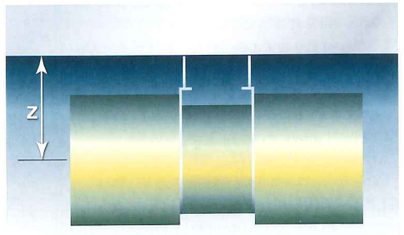
From [10] [11] it was found that from 5° to 10° there is an optimisation of the installation efficiency. This method has no remarkable application as far as the authors are aware.

Deflectors

As far as the authors know Kempf [2] studied the effect of deflection vanes on a pipe installed in a corner of a rectangular section in 1965.

The research was limited to establishing the effectiveness of an installation that uses deflectors. Effectiveness was surely increased due to the directing of the flow away from the wall. However from a fan point of view, the installation of deflectors on the outlet side or, even worse (in the case of a fully reversible jet fan), on both





Above, top: **Figure 1, arrangement with slanted silencer jet fans**
Above, bottom: **Figure 2, arrangement with standard jet fan**

the inlet and outlet, generates a negative effect on the fan performances through an increased drop, and especially on the inlet side, with a non uniform fluidodynamic load on the axial impeller.

Lotsberg [13] investigated the effect of deflectors on large, 1,500mm jet fans in a 6.6km long tunnel so the loss was limited.

The test was only done in one direction and they found a high energy loss inside the fan.

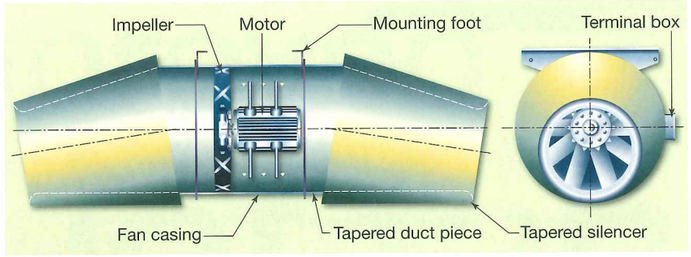
On a fully reversible fan this approach does not give any real benefit. Should the deflection vanes be attached at some distance from the fan ends, the pressure drop could be reasonably reduced but only a proportion of the spreading plume would be captured and turned, so again the benefit is reduced.

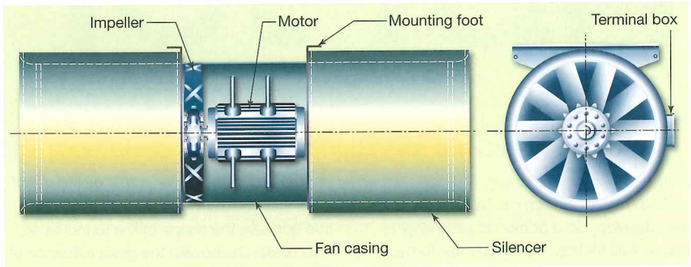
The use of the deflectors has been limited and discontinued. No further research has been undertaken.

Slanted Silencers

It is clear that the use of silencers has a beneficial effect on the k factor [9]. A further improvement is to slant the silencer down or away from the wall in the case of a niche positioned jet fan. This technical solution surely increases the k factor.

In situ measurements on the Balmenrain and Uznaberg tunnels in Switzerland were carried out by Pospisil et al [14] but flow measurement error was ± 19 per cent so the conclusion was not a consistent result due to the large tolerance span.





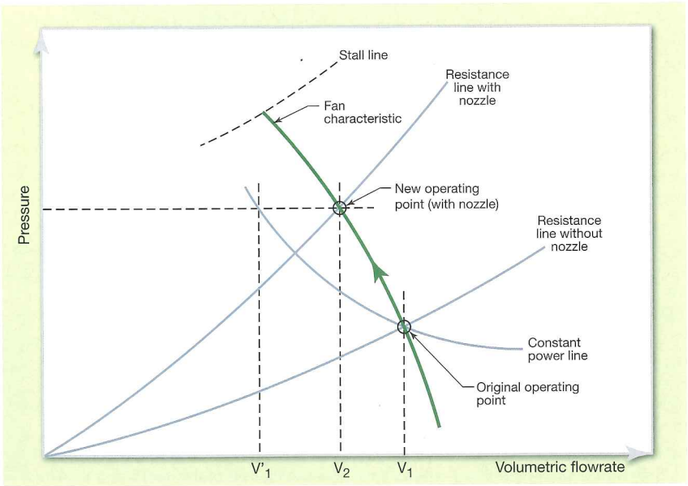
In a second in situ measurement of the Collembey Tunnel in Switzerland, Mart et al [15] improved the measurement technique reducing the uncertainty down to ± 12 per cent. Here the jet fans were installed in the corner of a rectangular tunnel section. It was concluded that the thrust of the slatted silencer jet fan was between 11 per cent to 21 per cent higher than the one of conventional straight jet fans.

The above installation was possible since the slanted silencers didn't interfere with tunnel clearance. If this is the case, then the two possible installation arrangements are feasible (see Figures 1 and 2, above).

These two solutions have the same k factor so there is no real need to install the slanted silencer jetfan type. Silencer slanting of 10° or more (normally it is between five and 25 per cent) means that the plume of the jet fan will be further from the vault of the tunnel, increasing the k factor, but at the same time it will hit the ground of the tunnel, generating a loss.

During a fire scenario, if the jet attaches itself to the tunnel floor and moves forward as a 'wall jet', the air velocity above the jet may be less than the critical velocity for smoke control, possibly leading to localised smoke back-layering.

Below: **Figure 3, axial fan performance curves**



Left, top: **Figure 4, tapered silencer jet fan arrangment**
Left, bottom: **Figure 5, non-tapered silencer jet fan arrangment**

This problem has been analysed by Betta et al [16] and the conclusion was in terms of energetic operating costs reduction:

- Optimal pitch angle 6° for a free tunnel.
- Optimal pitch angle between 2° to 4° for a tunnel with a traffic jam (e.g. congested traffic or fire scenario).

This issue may need to be addressed during the design stage of the project, possibly resulting in a higher number of jet fans in a fire scenario.

Due to the high silencer deflection angle the thrust developed along the longitudinal tunnel axis has to be corrected by the cosine of the angle.

The latest technical solution

Mojet

So far we have seen various technical efforts in order to maximise the momentum exchange between booster fans and the fresh air flow induced into the tunnel.

If we again consider formula one, we can appreciate that:

p = we have no control since it is a physical property of the air inside the tunnel

q_v, V_f = they are linked together in a directly proportional way. But should q_V be kept constant, and in some ways V_f increased, the result is an increase in the fan-developed thrust.

In more technical detail, Tarada [17] [18] describes the concept of the 'Momemtum Jet' (Mojet) with converging silencers outlets (nozzles) on one or both side of the fans depending on whether unidirectional or reversible jet fans are needed. So a significantly greater aerodynamic thrust can be obtained, with this converging nozzle arrangement, by accelerating the discharge air into a smaller outlet area.

Naturally there are losses generated by nozzles varying with a square law and power demand with a cubic law.

Axial fans have a steep performance curve, so the additional pressure drop moves up the working point of the fan while the volume flow reduction is not so remarkable, or it is possible to operate at lower blade pitch angle and higher pressure drops, while still delivering the required aerodynamic thrust.

The latter seems to cancel all the benefits but, it is not so, since moving upwards in the fan characteristic curve, the fan efficiency gets remarkably higher hence there is a benefit.

Another benefit comes from the inclination of the nozzles, not by as much as slanted silencers (around 5°) but enough to notably improve the k installation factor. It is important to note that the silencer downward inclination can be asymmetric, keeping the lowest silencer side at the same level, thus not increasing the fan envelope and keeping the same clearance as a standard jet fan.

We can summarise the variables:

- Asymmetric converging silencers.
- Inclination (about 5°).
- Blade pitch angle.
- Area restriction ratio, of around 1:6.

Playing with all these possibilities we have to optimise the combination, including the Kempf factor, to get the maximum performances out of the installed jet fan configuration.

A work example based on a 1.5km long tunnel can give a clear picture of the final benefits (see Table 1).

From the above Table 2 we can now highlight the advantages.

The above example has been developed with a number of CFD calculations and it has been optimised the many variables.

In this particular case, due to a small fan diameter, the thrust provided by the Mojet is lower than the one provided by a standard jet fan but the k factor and the absorbed power are better.

Table 1: Mojet benefits based on 1.5km tunnel

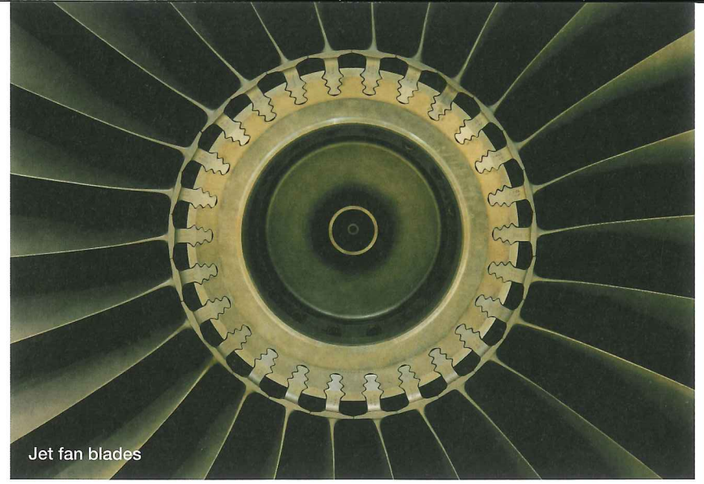
	Standard Jetfan	Mojet
Design thrust needed in the tunnel including the effect of air velocity inside the tunnel as per formula three	22,803N	
k factor Kempf	0.73	0.95
Static thrust needed from jetfans as per formula four	31,237N	24,003N

Table 2: Comparison of jet fan performance

	Standard Jetfan	Mojet
Jetfan diameter	710mm	
Jetfan thrust	822N	758N
Resulting Jetfan quantity	38	32
Jetfan absorbed power	328kW	28.6kW
Total power	1,246.4kW	915.2kW
Running hours per year	1000h	
kWh per year	1,246,400	915,200
Electricity cost	EUR 0.11/kWh	
Total energy cost per year	EUR 137,104	EUR 100,672

Table 3: Financial implications of jet fan choice

	Standard Jetfan	Mojet	Savings
Formula (4)	31,237N	24,003N	-23%
Quantity of jetfans	38	32	-16%
Total power	1,246.4kW	915.2kW	-27%
Total cost per year	EUR 137,104	EUR 100,672	-27%


Jet fan blades

For larger jet fan diameters of 1,000 to 1,250mm, the benefits can be achieved by increasing the thrust and the restriction area ratio. So for every fan diameter we should evaluate all the possible variables to find the best compromise:

- Blade pitch angle and hence volume flow
- Area ratio restriction and hence velocity hence thrust
- Power
- k factor

Additional benefits

This technical solution has other correlated positive effects. By reducing the number of booster fans we can reduce the installation costs. The cost of original equipment is also positively affected.

The electrical cable cost represents about 50 to 60 per cent of the total cost in a longitudinal ventilation system.

Having fewer booster fans and less power we can save in cable length and diameter. In Italy, the Italian Road Authority (ANAS) prescribes that the jet fans and correlated equipments have to withstand 400°C for two hours, hence the saving in this part of the installation is remarkable.

The last but not the least important point is that maintenance costs are not normally given much thought at the preliminary contract stage of a jet fan order. A reduction in the number of booster fans means less time inside the tunnel for inspection and maintenance purposes.

The flexibility of inclined converging nozzles can be done at any direction. On a horizontal plane, on a vertical plane, or a combination of the two. This feasibility allows the use of such technology in round, rectangular or any shaped tunnel section, even in niches.

Future steps

The Mojet has been demonstrated to have a sound physical basis, and the CFD analysis has supported this. However, true confirmation can only come with a real installation, or in a test carried out at a 1:1 scale. It is even better if the test is performed by a notified body that has no interest at all to manipulate the relevant measurements.

A 1:1 scale test was arranged for 2011 in a 600m long tunnel in Spain. This was changed to a test that will be carried out in Italy in 2012.

Conclusions

From the mid 1960s until the present day, a lot of dedicated research to establish the k factor more accurately has been carried out. Concurrently, various fan engineering technical solutions to achieve this have also been developed.

The latest, though surely not the final one, shows the best technical achievement, giving the possibility to increase the longitudinal ventilation performances, especially on energy consumption. This is a key figure to be considered for present and future design.

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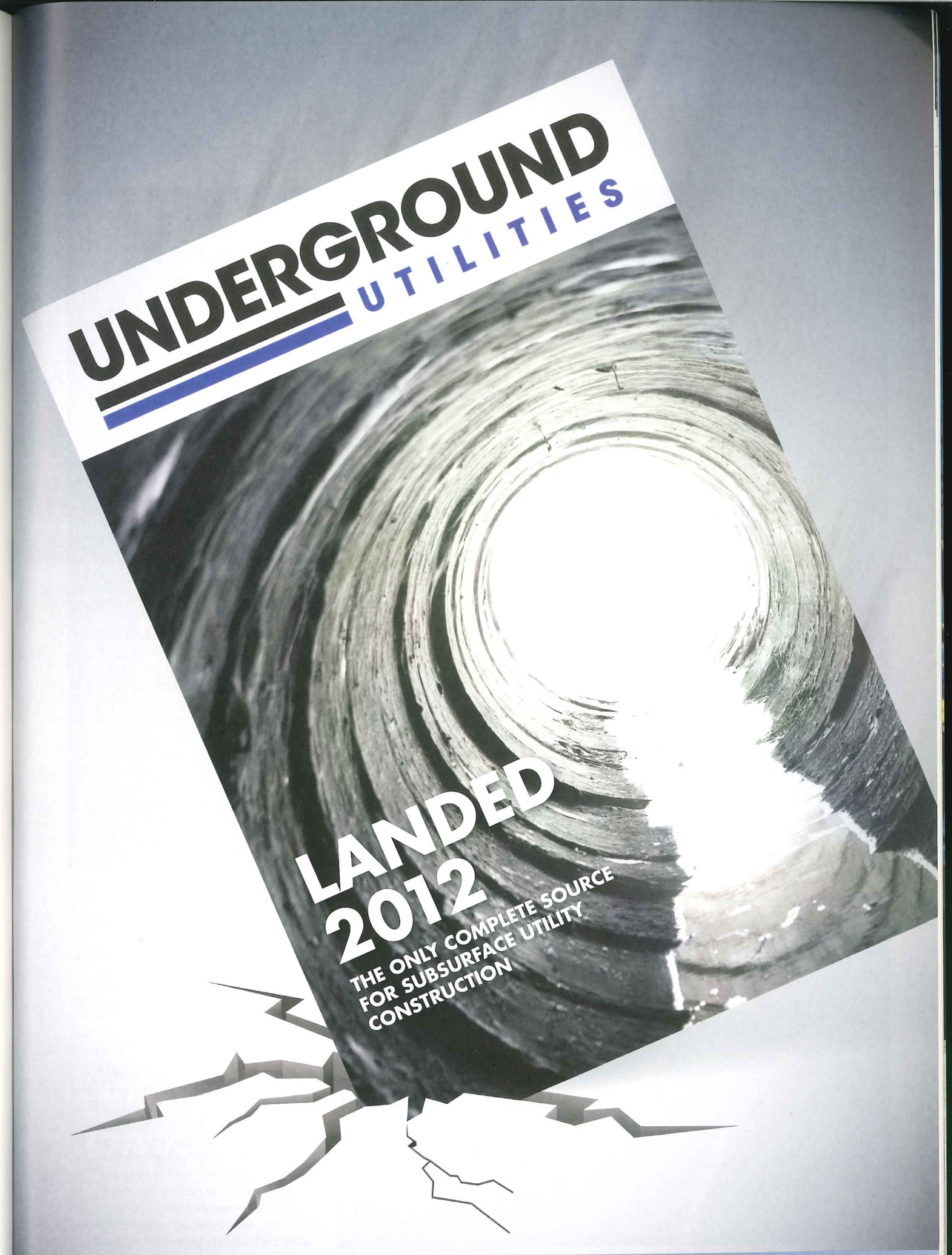

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New compressed air guidelines

The March BTS meeting marked the launch of the joint ITA and BTS guidelines for good working practice in high-pressure compressed air (HPCA). BTS input had been through its Compressed Air Working Group. Donald Lamont, principal author of the document, summarised the guidelines. Werner Burger, chief design engineer for Herrenknecht spoke on the problems of HPCA for a manufacturer. Tony Ridley of Tony Ridley Hyperbaric Associates outlined UK experience with HPCA. And Claus Mayer, managing director of Nordseetaucher gave an account of his experiences with HPCA

According to Donald Lamont high-pressure compressed air (HPCA) work is: "work in compressed air at pressures above historical statutory limits, which in most countries is between three and four bar (gauge), and which involves the use of breathing mixtures other than compressed natural air and can involve the use of saturation techniques". The differences between HPCA and traditional compressed air work includes the use of line-fed full-face masks for routine breathing of gases such as trimix in the excavation chamber, saturation exposures above six to seven bar, a hyperbaric living habitat possibly on the surface and transfer under pressure in the tunnel. Despite this the hyperbaric aspects of HPCA were not new, but they were new to tunnelling. HPCA work should be seen as an extension of existing compressed air working methods.

Recommendations of use

As with traditional compressed air work, the pressurising medium was compressed air. The number, pressure and duration of exposures should always be minimised whilst maintaining the overall safety of the work. The ITA/BTS guidelines do not recommend the use of HPCA, but only makes recommendations once a commercial decision to use HPCA had been made.

HPCA is being used or considered for contracts from Hong Kong and China, through Singapore and London to Vancouver and Seattle involving pressures from five to 10 bar and future contracts with theoretical maximum pressures of 10 to 15 bar are also being considered.

The ITA/BTS document is needed because HPCA is a relatively new and high risk technique which involves the transfer to the tunnelling industry of hyperbaric procedures more familiar in diving. There is currently no guidance on the technique.

The strength of the joint ITA/BTS publication lay in the background of the respective organisations. The ITA has some 65 member nations and is a recognised source of authoritative guidance in many countries around the world. The BTS Compressed Air Working Group (CAWG) is a multi-disciplinary group of hyperbaric specialists whose recognised expertise gives considerable technical credibility to the guidelines.

Guidelines

The guidelines are aimed at all parties involved in HPCA work including regulators, clients, designers, contractors and insurers. They are not a standalone document but draw heavily on other guidance sources including HSE L96/BTS Guidance, EN 12110, BS 6164:2011, diving industry guidance and other national standards.

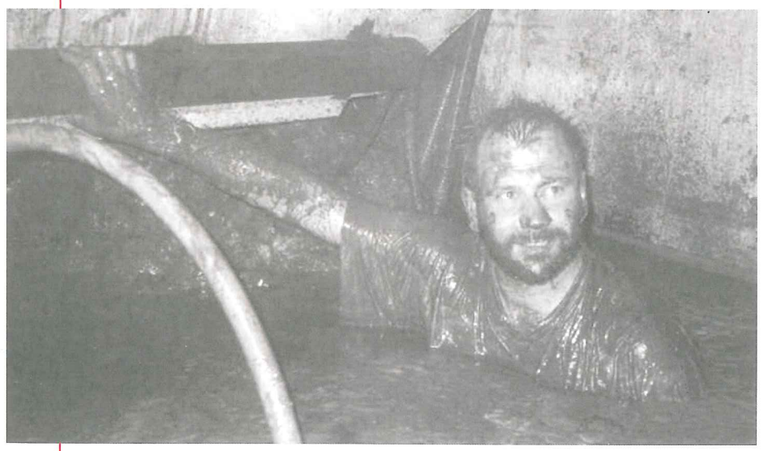
Terms such as 'saturation' and 'non-saturation' exposures along with 'transfer under pressure' are given. Non saturation exposure is a short duration exposure comprising a compression phase, a working period under pressure, followed by a decompression phase.

It does not involve any storage time in a hyperbaric living habitat. Whereas saturation is long duration exposure during which the person exposed lives under pressure and may make transfers into the working chamber.

Possible breathing mixtures such as nitrox, heliox and trimix are outlined. The physiological properties and problems of breathing oxygen, nitrogen and helium are described. The importance of partial pressure when considering exposure limits is stressed.

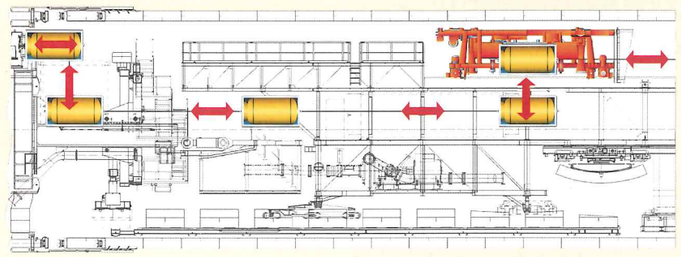
The recommended exposure limits for the various gases are: oxygen, partial pressure of 0.2 to 1.6 bar; nitrogen – partial pressure not exceeding 3.6 bar. Because total oxygen dose is also important, a maximum oxygen dose based on units of pulmonary toxic dose (UPTD) of 400 UPTD per day and 2,000 UPTD over seven days has been set. It is emphasised that these limits represented good practice but that not all contractors currently adhere to them.

Because of the discomfort of wearing masks and the use of small decompression locks, non-saturation exposures should be limited to a maximum of two hours

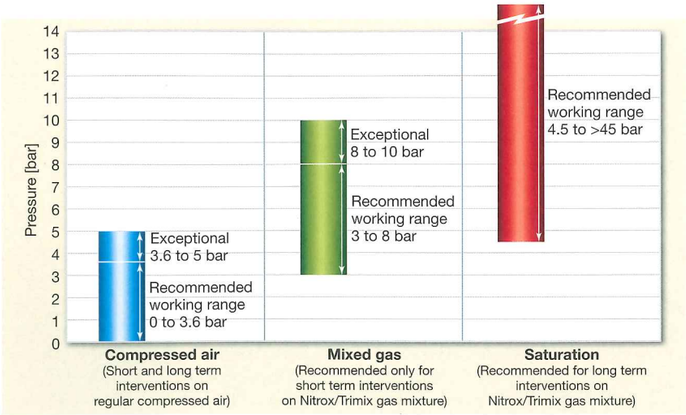


Below: The aim of the BTS CAWG/ITA guidelines is to make working conditions like this a thing of the past

Equipped for a submerged diving intervention



Left: Figure 1, crew shuttle transfer through trailing gear at Westershelde



Above: Figure 2, recommended compressed air methodologies based on pressure

decompression time, or a maximum of three hours under pressure.

Saturation exposures should be limited to 28 days for experienced saturation workers and 14 days for others.

The choice of non-saturation or saturation exposure is a commercial one based on the amount of work to be done and the working pressure.

Non-saturation exposures typically allowed 45 minutes working time at six bar. Saturation exposures should be considered from five bar upwards, and should be used from seven bar upwards.

The main safety issues include preventing sudden loss of pressure, selection and sourcing of gas mixtures, saturation and living under pressure along with worker selection and training.

In most jurisdictions, HPCA work would probably need some form of exemption, approval, dispensation and/or variance to allow it to be done legally, hence the guidance for regulators in the document. Clients had to recognise the costs of HPCA. Contractor selection should be on competence and capability with local diving contractors, not necessarily the best option. The ability to work safely in a tunnelling environment was paramount.

Questions from the floor

Roy Slocombe (BTS CAWG chairman) congratulated those involved in drafting the guidelines. He wondered what pressure limits the Panel foresaw in the future. Claus Mayer noted that 60 bar was the physical limit of pressure endurance. Tony Ridley commented that 18 to 36 bar was routine in commercial saturation diving. Werner Burger suggested that current capability was 10 bar with 15 bar possible in the future. Donald Lamont suggested there should be an incremental approach learning from experience at 5 to 10 bar before going to 15 bar.

Maurice Jones (*T&TI*) asked for confirmation, or not, that the immersion technique intervention at the face was as a result of unexpected ground pressure conditions. Werner Burger replied that saturation had been planned right from the start of the project.

Alan Myers noted that 30 years ago it was considered acceptable to go to 3.5 bar daily. This was no longer the case certainly in Hong Kong. He welcomed the capability to go to higher pressures to undertake emergency interventions but such exposures should not be considered routine. Designers should not be encouraged to think of HPCA interventions as a routine procedure. He applauded the publication of the guidelines. Tony Ridley pointed out that the guidelines specifically highlighted the need to minimise exposure.

Alastair Biggart asked about the involvement of insurance companies in regulating HPCA work and the attitude of HSE. Donald Lamont replied that he had drawn the attention of the re-insurers involved in the ITIG code, to the topic and to that evening's meeting. In addition at least one of the Classification Societies had produced rules specifically for hyperbaric chambers for tunnelling use. He did not ever see UK legislation specifically allowing HPCA. It would always be by exemption and approval. The Lee Tunnel was the only UK tunnel since compressed air was first used in 1851 to potentially require HPCA.

Types of intervention

Werner Burger began his presentation by describing types of interventions including inspection of face conditions and mechanical equipment in the excavation chamber, maintenance including replacement of cutting tools and wear protection elements, maintenance or cleaning of other equipment in the chamber, removal of natural or man-made obstacles and repair of structural damage. The intervention technique used depends on the pressure and duration of the exposure. For pressures up to 3.6 bar, short duration exposures in compressed air are normally used with decompression in the TBM airlock. In exceptional circumstances air could be used up to 4.5 bar. For short duration exposures up to 6 bar, mixed gas should be used for breathing with decompression in the TBM airlock. For long term interventions above 4.5 bar the use of saturation techniques with an above ground hyperbaric habitat is recommended. Personnel should be transferred in a pressurised shuttle between the habitat and the TBM airlock.

The TBM designer can opt for parallel or in-line compression chambers for workers to pass through the bulkhead. A major and ongoing problem that TBM designers have to overcome was lack of space to locate the chamber. For all countries however, the fundamental requirement at all times, excepting when the lock was actually in use, was to have one lock compartment open to free air whilst the other was open to the workings.

Exposure minimisation

Continuing the theme of minimising exposure, Werner Burger gives the design features to reduce the need for compressed air interventions. These include the increased durability of components in the excavation chamber; a better understanding of soil behavior in the excavation chamber; more and reliable information about excavation chamber and cutting tool conditions, engineered solutions for maintenance not requiring exposure to compressed air and the use of safe havens, blocks of treated ground in which to carry out maintenance. Other design features aimed at reducing exposure include remote visual inspection techniques such as using an endoscope from within the air bubble chamber or from behind the bulkhead; fixed cameras in the excavation chamber; a range of wear detection systems covering both tools and the cutterhead structure. Systems which allowed maintenance to be undertaken in free air includes, on mixshields, a gate to isolate the crusher and suction intake from the slurry in the air bubble chamber. On large cutterheads it was possible to fit the tools within housings into which they could be withdrawn for maintenance. The housing could then be sealed against the outside pressure and thus permit tools to be changed from within the spokes of the cutterhead in free air. This system was first used on the Fourth Elbe Tunnel in 1996.

Lee Tunnel HPCA

Thames Water's Lee Tunnel is the first UK project to potentially require HPCA techniques.

For much of its length the Lee Tunnel will be driven in chalk, however there is a short length close to the end of the drive where the Thanet Sands are predicted to dip into the tunnel horizon. Contingency planning to be able to undertake maintenance interventions in the cutterhead was a contractual requirement applicable over the full length of the drive. Within the chalk, it is planned that by a combination of pumping and/or ground treatment, routine interventions could be conducted in free air or in compressed air at pressures not exceeding 3.45 bar.

However, where an intervention is required within the Thanet Sands, there is a potential for water pressures up to 6.9 bar to be encountered. It was a contingency planning exercise for this scenario, which identified the potential use of HPCA on the Lee Tunnel Project. HPCA options that have been considered includes the use of nitrox for saturation exposures, however the useful range of nitrox was too limited to make this a viable option. This left the possibility of non-saturation exposures or saturation exposures using heliox or trimix.

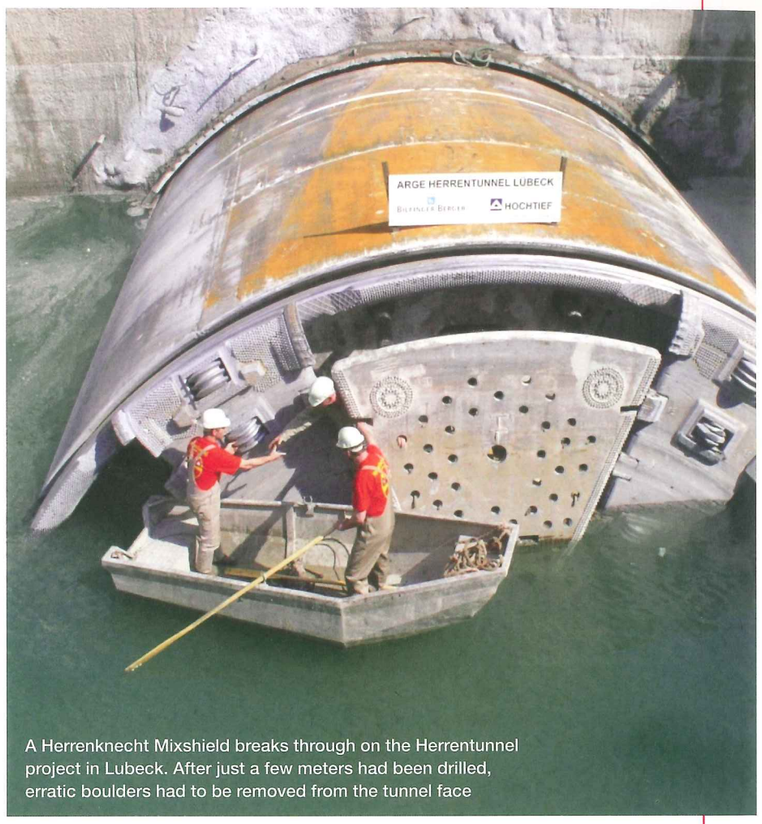
Compressed air could be used above 3.45 bar, but at that pressure it became increasingly unsafe because of the risk of nitrogen narcosis and the high gas density which was why it was not recommended in the ITA/BTS guidelines.

Saturation options would require high establishment costs which had to be balanced against a very low possibility of use and were thus eliminated.

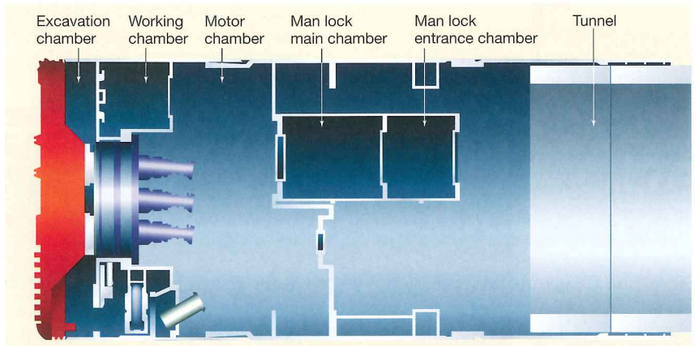
Non-saturation options had a relatively low establishment cost and with the limited possibility of their adoption became a cost effective option. Trimix – a mixture of oxygen, nitrogen and helium is the preferred breathing mixture. Ridley's company has been developing this technique for some time prior to Lee Tunnel for contingency interventions on projects in other countries.

The main advantages of trimix is the control of nitrogen narcosis by limiting the proportion of nitrogen in the mixture, a lower gas density by incorporating helium in the mixture to reduce the work of breathing and control of oxygen partial pressure by adjusting the proportion of oxygen in the mixture by mix adjustment. In addition the higher thermal conductivity of helium could be of benefit in reducing heat build up in the working chamber and only minimal voice distortion was expected.

There are no dedicated trimix decompression tables so heliox tables will be used. This gives a further benefit as an



A Herrenknecht Mixshield breaks through on the Herrentunnel project in Lubeck. After just a few meters had been drilled, erratic boulders had to be removed from the tunnel face



Left: Figure 3, TBM section diagram showing hyperbaric setup

improved decompression outcome has been predicted from research, against equivalent heliox exposure. This is due to asymmetry in the take up and wash out of helium in the body.

The key procedural aims for the Lee Tunnel were to adapt existing validated procedures for trimix use; to provide realistic working time for non-saturation exposures; to minimise technical and logistical complications; to minimise oxygen dosage and to maximise safety along with worker comfort. The make up of the trimix would be determined by limiting values for nitrogen and oxygen with the balance made up with helium. Although the mixture can be varied with pressure, a single mixture for use over the full working range is preferable.

Procedures

The Work in Compressed Air Regulations 1996, limit exposure to a maximum of 3.45 bar. Because of this and in order to be allowed to undertake HPCA work, applications have had to be made to the HSE for an exemption under Regulation 21 to exceed the maximum pressure of 3.45 bar permitted under Regulation 11(2) and for approval under Regulation 11(1) of a regime for decompression following exposures using trimix at up to 6.9 bar.

That process has been somewhat protracted and onerous as it involved exemption from existing legislation. Additionally it is the first time such an exemption and approval has been requested. Until publication of the ITA/BTS guidelines, no appropriate guidance had been available. Because of all this, the Health and Safety Executive (HSE) requested extensive justification and validation of the procedures and their development, along with access to supporting research and information on the mitigation measures that would be employed to avoid or reduce the use of HPCA. The process remains ongoing.

Diving experience

Claus Mayer has had extensive international experience in HPCA work. His early experience had been as a saturation and experimental trials diver at pressures to 60 bar. He also has extensive experience of compressed air tunnelling. Amongst notable tunnel projects on which he had worked were the Fourth Elbe tunnel, where both compressed air and diving work in bentonite had been done in the cutterhead.

Mayer also worked on Westerschelde which was the first tunnel project to use saturation techniques. In his experience, the main reasons for interventions were maintenance of the cutterhead.

Partial pressure nitrogen (bars abs)

Pressure bar gauge	N2% 50	48	46	44	42	40	38	36	34	32	30
3.4	2.20	2.11	2.02	1.94	1.85	1.76	1.67	1.58	1.50	1.41	1.32
3.6	2.30	2.21	2.12	2.02	1.93	1.84	1.75	1.66	1.56	1.47	1.38
3.9	2.45	2.35	2.25	2.16	2.06	1.96	1.86	1.76	1.67	1.57	1.47
4.2	2.60	2.50	2.39	2.29	2.18	2.08	1.98	1.87	1.77	1.66	1.56
4.5	2.75	2.64	2.53	2.42	2.31	2.20	2.09	1.98	1.87	1.76	1.65
4.8	2.90	2.78	2.67	2.55	2.44	2.32	2.20	2.09	1.97	1.86	1.74
5.1	3.05	2.93	2.81	2.68	2.56	2.44	2.32	2.20	2.07	1.95	1.83
5.4	3.20	3.07	2.94	2.82	2.69	2.56	2.43	2.30	2.18	2.05	1.92
5.7	3.35	3.22	3.08	2.95	2.81	2.68	2.55	2.41	2.28	2.14	2.01
6.0	3.50	3.36	3.22	3.08	2.94	2.80	2.66	2.52	2.38	2.24	2.10
6.3	3.65	3.50	3.36	3.21	3.07	2.92	2.77	2.63	2.48	2.34	2.19
6.6	3.80	3.65	3.50	3.34	3.19	3.04	2.89	2.74	2.58	2.43	2.28
6.9	3.95	3.79	3.63	3.48	3.32	3.16	3.00	2.84	2.69	2.53	2.37
7.2	4.10	3.94	3.77	3.61	3.44	3.28	3.12	2.95	2.79	2.62	2.46
7.5	4.25	4.08	3.91	3.74	3.57	3.40	3.23	3.06	2.89	2.72	2.55
7.8	4.40	4.22	4.05	3.87	3.70	3.52	3.34	3.17	2.99	2.82	2.64
8.1	4.55	4.37	4.19	4.00	3.82	3.64	3.46	3.28	3.09	2.91	2.73
8.4	4.70	4.51	4.32	4.14	3.95	3.76	3.57	3.38	3.20	3.01	2.82
8.7	4.85	4.66	4.46	4.27	4.07	3.88	3.69	3.49	3.30	3.10	2.91
9.0	5.00	4.80	4.60	4.40	4.20	4.00	3.80	3.60	3.40	3.20	3.00
9.3	5.15	4.94	4.74	4.53	4.33	4.12	3.91	3.71	3.50	3.30	3.09
9.6	5.30	5.09	4.88	4.66	4.45	4.24	4.03	3.82	3.60	3.39	3.18
10.0	5.50	5.28	5.06	4.84	4.62	4.40	4.18	3.96	3.74	3.52	3.30

At 2.5 bar gauge air has a PPN2 of 2.76 bar for routine use this has been deemed a reasonable equivalent nitrogen limit
At 3.0 bar gauge air has a PPN2 of 3.16 bar this should be considered a maximum equivalent nitrogen limit

Partial pressure oxygen (bars abs)

Pressure bar gauge	O2% 16	17	18	19	20	22	22	23	24	25	26
3.4	0.70	0.75	0.79	0.84	0.88	0.92	0.97	1.01	1.06	1.10	1.14
3.6	0.74	0.78	0.83	0.87	0.92	0.97	1.01	1.06	1.10	1.15	1.20
3.9	0.78	0.83	0.88	0.93	0.98	1.03	1.08	1.13	1.18	1.23	1.27
4.2	0.83	0.88	0.94	0.99	1.04	1.09	1.14	1.20	1.25	1.30	1.35
4.5	0.88	0.94	0.99	1.05	1.10	1.16	1.21	1.27	1.32	1.38	1.43
4.8	0.93	0.99	1.04	1.10	1.16	1.22	1.28	1.33	1.39	1.45	1.51
5.1	0.98	1.04	1.10	1.16	1.22	1.28	1.34	1.40	1.46	1.53	1.59
5.4	1.02	1.09	1.15	1.22	1.28	1.34	1.41	1.47	1.54	1.60	1.66
5.7	1.07	1.14	1.21	1.27	1.34	1.41	1.47	1.54	1.61	1.68	1.74
6.0	1.12	1.19	1.26	1.33	1.40	1.47	1.54	1.61	1.68	1.75	1.82
6.3	1.17	1.24	1.31	1.39	1.46	1.53	1.61	1.68	1.75	1.83	1.90
6.6	1.22	1.29	1.37	1.44	1.52	1.60	1.67	1.75	1.82	1.90	1.98
6.9	1.26	1.34	1.42	1.50	1.58	1.66	1.74	1.82	1.90	1.98	2.05
7.2	1.31	1.39	1.48	1.56	1.64	1.72	1.80	1.89	1.97	2.05	2.13
7.5	1.36	1.45	1.53	1.62	1.70	1.79	1.87	1.96	2.04	2.13	2.21
7.8	1.41	1.50	1.58	1.67	1.76	1.85	1.94	2.02	2.11	2.20	2.29
8.1	1.46	1.55	1.64	1.73	1.82	1.91	2.00	2.09	2.18	2.28	2.37
8.4	1.50	1.60	1.69	1.79	1.88	1.97	2.07	2.16	2.26	2.35	2.44
8.7	1.55	1.65	1.75	1.84	1.94	2.04	2.13	2.23	2.33	2.43	2.52
9.0	1.60	1.70	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60
9.3	1.65	1.75	1.85	1.96	2.06	2.16	2.27	2.37	2.47	2.58	2.68
9.6	1.70	1.80	1.91	2.01	2.12	2.23	2.33	2.44	2.54	2.65	2.76
10.0	1.76	1.87	1.96	2.09	2.20	2.31	2.42	2.53	2.64	2.75	2.86

Partial pressure of oxygen should not exceed 16 within routine operational range
Partial pressure of oxygen should not exceed 18 within exceptional operational range

Above: Figures 4 and 5, partial pressure tables for gases within the mix. The mix can be adjusted with pressure, but ideally a mix that can be used over a viable pressure range is established

Lessons from Westerschelde

Saturation working at Westerschelde had necessitated the use of transfer under pressure techniques between the surface habitat and the TBM. Other work in the cutterhead could include inspection and assessment of tool damage. Occasionally the removal of obstructions ahead of the face was required. Cutting and welding as a high risk activity in the cutterhead. Lack of inspection and routine maintenance could result in major repairs being necessary. Sometimes this required the construction of a small heading across the front of the cutterhead from which the work could be carried out. Mayer warns of some of the hazards of HPCA work including fire and blow out. Water mist is the most effective fire fighting medium for airlocks, according to Mayer. Detailed safety rules for HPCA were required. Total oxygen dose should be limited with air breaks provided every 30 minutes. Only decompression tables incorporating air breaks should be considered. Air locks should be kept clean and free from rubbish.

Oxygen concentration in the locks should be monitored and kept within recognised limits. A further essential precaution was the provision of a recompression chamber on site.

Rapporteur: Donald Lamont

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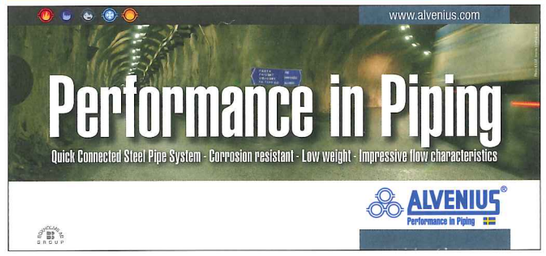

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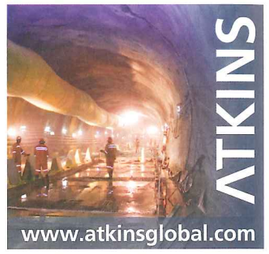

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dates & events

10-11 SEPTEMBER 2012
Baku Tunnelling Congress, Azerbaijan
'Tunnels & Underground Infrastructure of Urban Areas' including extension of metros and tunnels in Azerbaijan, Russia, Kazakhstan, etc. Full paper submission deadline 1 June. Organised by the Azerbaijan Tunneling Assoc with the French Tunneling and Underground Space Association (AFTES). For more info email baku.conference2012@azta-asso.com or view www.azta-asso.com.

18-21 SEPTEMBER 2012
'The Tunnel Connects' Eastern European Tunnelling Congress, Budapest, Hungary
The Hungarian Tunnelling Association is organising this congress to share experiences and exchange knowledge of design, construction management, research results and technical developments of tunnels completed by the regional associations and experts. The planned regional sub-European conference is open to all other co-organizers and participants as well as to those who having ongoing or completed projects, research works in this area. More information at http://www.eetc2012budapest.com or contact Diamond Congress Ltd., tel.: +36 1 2250210 or email diamond@diamond-congress.hu.

2-4 OCTOBER 2012
No-dig Live 2012, Coventry, UK
The UK's major biennial event showcasing trenchless technology and the best products and services applied to the new installation and refurbishment of underground utilities. 2012 marks the eleventh exhibition. More information at: www.nodiglive.co.uk or for visitor and exhibition enquiries, tel: Tel: +44 (0) 20 8876 1881.

8-10 OCTOBER 2012
Intermat Middle East, Abu Dhabi National Exhibition Centre
See www.intermat-middleeast.com or tel.: +33 1 76 77 12 08.

17-20 OCTOBER 2012
Montreal TAC 2012, Canada
'Tunnels & Underground Spaces: Sustainability & Innovations: Sustainability & Innovations', organised by the Tunneling Association of Canada. For more info contact Wayne Gibson, conference manager, c/o Gibson Group Association Management, Richmond, BC, tel: +(604) 241-1297, email info@tac2012.ca or see www.tac2012.ca.

23-24 OCTOBER 2012
Trenchless Live 2012, Royal Melbourne Showgrounds, Australia
Live event for the Australasian trenchless industry, featuring hands-on and live exhibition and demonstrations of trenchless equipment. Info at: www.trenchless2012.com, or tel: +61 3 9248 5100.

7 - 9 NOVEMBER 2012
13th World Conference of ACUUS, Marina Bay Sands, Singapore
ACUUS presents 'Underground Space Development – Opportunities and Challenges' to focus on new opportunities in developing underground space as sustainable development. More info from E-Quezt Concierge, Singapore tel.: +(65) 6271 2453, email info@acuus2012.com or see http://www.acuus2012.com.

22 JANUARY 2013
11th George A Fox NY Construction Conference
Graduate Center, City University of New York, US. Organised by the SME - Society for Mining, Metallurgy & Exploration and sponsored by the Underground Construction Assoc of the SME. For more details tel.: +1 (303) 948-4200, fax: +1 (303) 979-3461, email meetings@smenet.org or see www.smenet.org

28-29 FEBRUARY 2013
Tunnel Design & Construction Asia 2013, Hong Kong
The conference is a platform for tunnelling industry stakeholders to discuss and share best practices in constructing efficient and sustainable tunnel infrastructure. More info at: http://www.tunneldesignconstruction.com, or email: enquiry@iqpc.com.sg

18-20 MARCH 2013
TU-Seoul 2013
Intl Symp on Tunnelling & Underground Space Construction for Sustainable Development. Full papers due 31 July 2012. Visit: www.tunnel.or.kr.

22-24 APRIL 2013
12th International Conference - Underground Construction Prague 2013, Czech Republic
The conference consists of technical exhibition, poster session and technical excursions. More info at: www.ita-aites.cz, or tel: +420 296 337 181.

27-29 MAY 2013
Suissetraffic, Geneva, Switzerland
Switzerland will host the 60th International Association of Public Transport world congress in Geneva. The trade fair brings together the railway, aerial cableway and tunnel construction sectors under one roof. More info at: www.suissetraffic-expo.ch, further info at: www.uitpgeneva2013.org, or tel: +41 31 340 11 11.

31 MAY- 7 JUNE 2013
WTC 2013, Geneva, Switzerland
World Tunnel Congress at International Conference Centre. Organised by Swiss Tunnelling Society. For more information tel.: +41 (0)81 725 31 32, email sia-fgu@swisstunnel.ch or see www.wtc2013.ch.

16-19 JUNE 2013
Strait Crossings Conf, Norway
At Radisson Blu Royal Hotel, Bergen. Organised by Norwegian Public Roads Administration and features extreme crossings and new technologies.For more details tel: +47 22 94 75 00, email siri.engen@tekna.no or see www.SC2013.no.

23-26 JUNE 2013
Rapid Excavation & Tunneling Conf (RETC), Washington DC, US
Wardman Park Marriott. Organised by the Society for Mining, Metallurgy & Exploration. For more details tel: +1 (303) 948-4200 or email: meetings@smenet.org.

A DATE TO REMEMBER...

If you know of a tunnelling related conference, event, seminar or exhibition, which 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: Editor, 'Tunnels & Tunnelling International', Boundary House, 91-93 Charterhouse Street, London, EC1M 6HR, United Kingdom.
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ALL BTS MEETINGS ARE AT THE INSTITUTION OF CIVIL ENGINEERS, LONDON, UNLESS OTHERWISE STATED, AT 17:30 FOR 18:00 UNTIL APPROX. 19:30. TRADITIONAL BAR AND SNACKS WILL BE AVAILABLE AFTERWARDS.

2-6 JULY 2012
BTS Tunnel Design & Construction Course, University of Warwick, England
In-depth introduction to the majority of tunnelling-related subjects, presented by industry experts. Ideal for young consulting and contracting engineering starting a career in tunnelling, and others (eg clients and insurance professionals) with an involvement in tunnelling.

20 SEPTEMBER 2012
URUP - Ultra Rapid Under Pass - An innovative shield tunnelling technology
Makoto Kanai - vice-president - & Akhiro Nicihimori - senior tunnel engineer, both of Obayashi, present the URUP shaftless shield method, especially for congested area, challenging ground conditions and stringent physical and environmental constraints. The presentation will describe how the URUP concept was developed, mechanisms of ground control under shallow cover and review projects where it has been successfully used.

OCTOBER/NOVEMBER
Annual Health & Safety Course
At ICE, London. Details to be announced.

4 OCTOBER 2012
BTS Young Members: Numerical modelling

1 NOVEMBER 2012
BTS Young Members: AGM and Design of openings in tunnels and shafts

18 OCTOBER 2012
Tunnel Security and Blast Analysis
Blast protection design of transport tunnels. Speaker to be announced.

15 NOVEMBER 2012
EPBM & Slurry Tunnelling Principles
Safe operational protocols for full-face TBMs, Speaker to be announced.

20 DECEMBER 2012
Debate: 'This house believes tunnel projects in the UK are over-staffed and over-specified'

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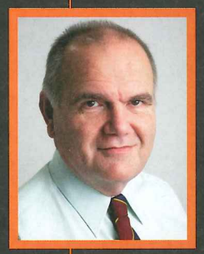

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