FEBRUARY 2012

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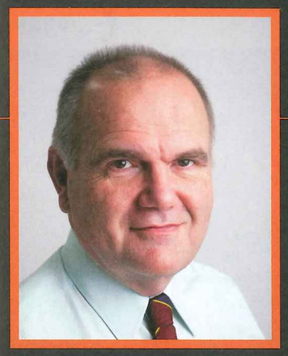

comment

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Gift horses from classical scholars?

It is to be hoped that our international readers will forgive the official magazine of the BTS for concentrating this month's comment on British tunnelling matters, but to paraphrase a 1960s Prime Minister, 'we've never had it so good' – or so it seems.

Now that the domestic and international tunnelling industry is very busy with several major projects, more is being thrust upon us. But why?

It is surely no coincidence that London mayor Boris Johnson has announced a new road tunnel under the Thames at Silvertown during the lead up to the mayoral elections. His enthusiasm for cross-Thames transport solutions was hardly so great when he cancelled the planned Thamesmead bridge project when he came to power in 2008. But maybe I do him an injustice, and he is actually a tunnelling convert. One would certainly hope so as Crossrail and Tideway progress. He did, after all, call for tunnelling through London for HS2, the controversial high-speed rail link to the Midlands and the northwest.

Still focusin on HS2, what of the extra tunnelling that has suddenly been added to plans for its preferred route. One would like to think that politicians of all persuasions have now become aware of the 'green' credentials' of tunnelling compared to surface and open-cut routes. But more likely is the fact that there was a need to 'buy off' a serious surge of protest from politicians and influential establishment figures, if not voters, based along the route itself.

Fortunately the great scar of cutting through the Chilterns 'Area of Outstanding Natural Beauty' around Great Missenden has at last been replaced by tunnel. Bored or cut and cover though? Such areas are an increasingly rare asset in the crowded UK, and enjoyed by many more than 'nimby' residents. Tunnelling can play its part in preserving them as it has done in several cases in other countries.

Those of us who have been around long enough to remember the many false starts to the Channel Tunnel (or at least read about the earlier ones) will know that politicians can easily take away with one hand what they have given to you before with the other. And whilst politicians ponder and argue, the uncertainty of 'feast or famine' projected onto the supply industry does nothing for security and development of business. As a result of the British talent for bad timing, international rather than British-based interests are serving many of the current and future tunnelling projects, at least in terms of manufacture. Fortunately British tunnelling skills, unlike most supply industry, have survived, and will continue to do so if nurtured.

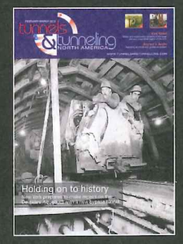
Perhaps the long lead-times set down for the new tunnelling of HS2 and under the Thames will allow entrepreneurs the time to invest in a renaissance of a British-based tunnelling supply industry, but don't hold your breath. Despite the current resurgence of activity there are many, much larger markets worldwide that command greater attention and offer comparative economies.

It is said that one should never look a gift horse in the mouth, for fear of showing ingratitude. But, if the Trojans had looked their gift horse from the Greeks in the mouth, they may have survived! As all tunnellers know, we must progress with caution, but, hopefully, continue to progress at a good, steady pace.

Maurice Jones

contents

On the cover:
The Helsinki to Espoo metro project, driven 14km through mostly hard granite. See page 30 for feature



In the supplement:
A bypass tunnel is in the works for the aging and leaking Delaware Aqueduct

More tunnelling for High Speed 2

GREAT BRITAIN

The UK Government approved the country's High Speed Two (HS2) rail line to link Birmingham with London last month. It also announced an expansion to the tunnelled sections in response to environmental concerns.

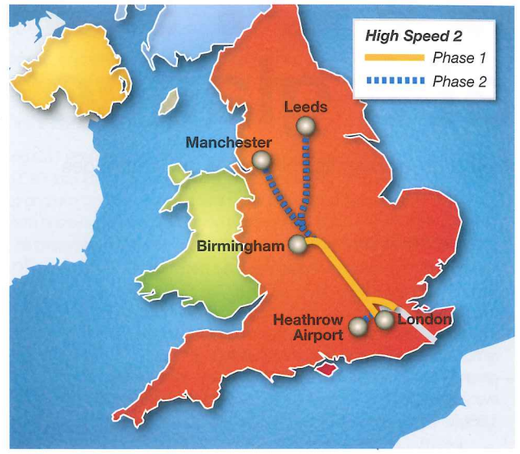
Transport secretary Justine Greening announced that there would be a longer, continuous tunnel from Little Missenden to the M25 through the Chilterns, a new 4.4km bored tunnel along the Northolt Corridor to entirely avoid major works to the Chilterns Line, a longer green tunnel to reduce impacts around Wendover, and an extension to the green tunnel at South Heath. Extension of the tunnel past Chipping Warden and Aston Le Walls would also be required along with a curving of the route to avoid a cluster of heritage sites around Edgcote.

The GBP 17bn (USD 26.31bn) first phase of HS2 linking London with Birmingham could be built by 2026. It would run for approximately 160km and greatly improve journey times. Later work, taking the route on to Manchester, Leeds and even Scotland would take until at least 2033 and bring the estimated cost of the project to GBP 32bn (USD 49.5bn).

The project has faced opposition. Residents of the Chiltern Hills, and area of outstanding natural beauty to the north of London have attempted to block the scheme. Critics of the project have also argued that overcrowding can be eased through improvements to the existing line, with longer trains and fewer first class carriages. A review of alternatives by Network Rail found that neither would provide the required capacity.

Greening said, "I have decided Britain should embark upon the most significant transport infrastructure project since the building of the motorways by supporting the development and delivery of a new national high speed rail network. By following in the footsteps of the 19th century railway pioneers, the Government is signalling its commitment to providing 21st century infrastructure and connections – laying the groundwork for long-term, sustainable economic growth.

"Today I have presented to Parliament a full account of my decisions titled High Speed Rail: Investing in Britain's Future – Decisions and Next Steps. My Department has published a series of supporting documents, which set out in further detail the basis on which I have reached my decisions."



Above: The HS2 initial phase will connect London with Birmingham

BTS chairman Bob Ibell said, "I am delighted that we are recognising the benefits both economic and environmental of going underground. This is a message that the BTS and the ITA has been promoting for some years

"Plainly this kind of tunnelling does not necessarily have the challenges of deep bored tunnelling under the City of London, but the challenge of tunnelling in the urban environment, and minimising the disruption while delivering an economic solution remains.

Ibell added, "It should fit in well with the completion of tunnelling on Crossrail and, if it adheres to its programme, will start to provide the firm programme of work which IUK in their report on infrastructure costs identified as being necessary to encourage employers to invest in training and development of capabilities and people."

All of the Department for Transport's material is available at www.dft.gov.uk/highspeedrail

Malaysian institute warns against non-professional practice owners

MALAYSIA

The Institution of Engineers Malaysia (IEM) has warned the government over plans to allow 'non-professionals' to own and operate consultancy practices. According to the IEM, thousands of Malaysian engineers will have to end their businesses if restrictions are lifted. IEM president Vincent Chan said, "If just anyone is allowed to own 100 per cent equity in an engineering consultancy practice, even a fishmonger can start a consultancy firm and hire engineers to work for him. This can be avoided by ensuring that the equity of such practices remains in the hands of engineers."

The plans were announced during Prime Minister Datuk Seri Najib Tun Razak's 'Budget 2012' speech in which he said the right to own 100 per cent of a consultancy practice would be opened up to all.

Chen said that the IEM was not against the promotion of free trade but such moves must be confined to professional engineers only. He added that lawmakers should heed the concerns of engineers.

There were approximately 3,500 engineering consultancy firms in Malaysia as *T&TI* went to press.

Chen said decisions could be compromised, "Consumers can be adversely affected if safety standards are compromised as a result of having non-professional engineers owning the practice."

News in brief

Militant escape tunnel
Up to 15 Al-Qaida militants have escaped through a tunnel from a prison in Aden, the southern port city of Yemen. A prison officer reported that the men passed through the tunnel, about 40m long, emerging near a petrol station outside the prison perimeter. It was the second large-scale militant breakout in 12 months. A dozen escapees were convicted of robbing a bank and killing security officials.

World at a glance

Project developments, milestones and challenges

STEWART, CANADA

Rehabilitation has been completed on the 17km-long Granduc Copper Project haulage tunnel. The project was the first rehabilitation work on the tunnel in over a quarter of a century. Work mainly involved spot bolting, railway tie removal and shotcreting wherever there was a fall of ground. The tunnel is 16 by 16ft (4.9 by 4.9m) but switches every kilometre. The contract value was CAD 5M (USD 4.93M).

"This is a milestone achievement in our efforts to move the Granduc Copper project forward," said Mike Sylvestre, president, CEO and director of client and owner, Castle Resources.

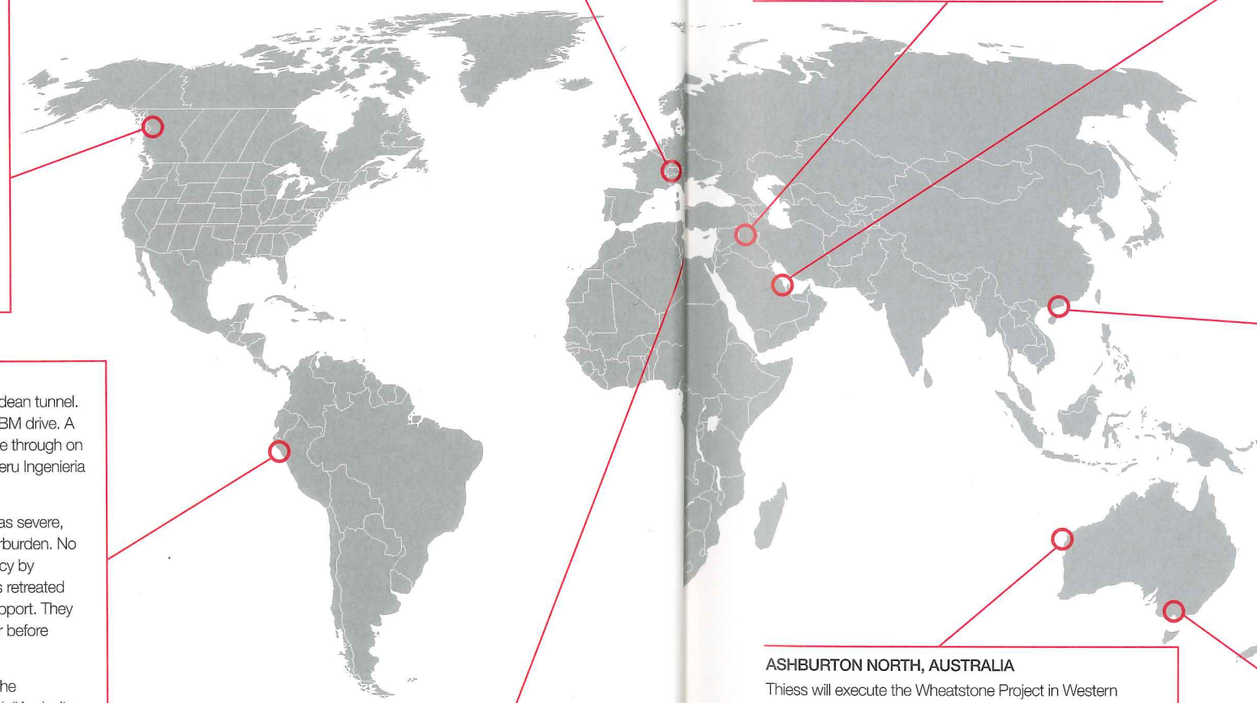
"The ability to safely access the mine now clearly positions Castle as an aggressive mine redevelopment story, with the next objective being the rehabilitation of strategic underground levels and exploration drifts for further copper resource definition."

VIGANA, SWITZERLAND

Alptransit Gotthard has executed the final blast on the north drive of the Ceneri base tunnel. At 2:50pm on 21 December, the Swiss town of Vigana saw the final explosion on the 670m section of tunnel.

Walter Bernardi, chief construction officer for the Ceneri Base Tunnel at Alptransit Gotthard said, "Although excavation work from the north portal at Vigana and the south portal at Vezia is now complete, work on realisation of the Ceneri Base Tunnel continues at full speed. [At the end of 2011], around 40 per cent of the 39.8km-long tunnel system [had] been fully excavated."

Tunnel lining began early this year as well as other fitting out work. An Alptransit Gotthard spokesman added, "From the new year, excavation of the Ceneri Base Tunnel will continue only from the intermediate heading at Sigirino. Driving work is expected to be completed in 2016, after which the railway systems will be installed. The Ceneri Base Tunnel is scheduled to open for commercial operation in December 2019."



OLMOS, PERU

Four years of tunnelling has concluded at the Olmos trans-Andean tunnel. Over 16,000 rock bursting events resulted from the 12.5km TBM drive. A 5.3m-diameter Robbins Main Beam TBM was used and broke through on 20 December. The contractor was locally based Odebrecht Peru Ingenieria y Construccion.

Some 17 per cent of the rock bursting events were classified as severe, due to the high rock stresses caused by up to 2,000m of overburden. No injuries were reported. A pre-drilling and sequential boring policy by Odebrecht may have helped with this. During a push, workers retreated 40m back from the face via an area behind the cutterhead support. They would wait for 30 minutes to allow rock deformations to occur before returning to the face.

A Robbins spokesman described the geology as 'extreme'. The spokesman added, "Andesite, dacite, tuff, schist, and pyroclastic breccias up to 250MPa UCS were unforeseen and required in-tunnel machine modifications as rock bursting became more severe.

Odebrecht production manager Hiroshi Handa said, "I am proud to have an extraordinary working team – [working together through] all of the difficulties and challenges."

ROSETO CAPO SPULICO, ITALY

An EUR 791M (USD 1.01bn) Italian National Road contract has been claimed by a 60-40 joint venture of Astaldi and Impregilo. The contract is for mega lot three of the Jonica National Road (NR-106).

An Astaldi spokesman said, "The project will upgrade the section of the Jonica National Road running from the junction with National Road 534 to Roseto Capo Spulico, running for 38km. Works will include 13km of tunnels.

DOHUK, IRAQ

Eleven inmates have escaped Zirga Jail in northern Iraq through an 80m tunnel. The men who absconded last month were serving a range of sentences, from five years imprisonment to death, for crimes ranging from drug offences to murder.

The governor of the prison, located in the northern, Kurdish province of Dohuk said that he was surprised by the events.

Sagvan Jameel, head of Zirga Jail said, "Eleven prisoners have escaped. They dug an 80m-long tunnel and escaped through it. The prisoners did not leave any traces of how they dug the tunnel, we are surprised."

LUSAIL, QATAR

Samsung C&T will tunnel the 'transport centrepiece' for Qatar's newest planned city, Lusail. The USD 296M contract awarded on Friday required the construction of a 10.7km motorway, with 1.5km underground. The project will run for a total duration of 30 months.

The Singaporean contractor was the preferred bidder out of 26 other submissions. The company said its experience on the Abu Dhabi Salam Underground Motorway and the Singapore Marina Coastal Expressway. In November 2011 it was also awarded the Lusail Bridges Project.

A Samsung C&T spokesman added, "Starting with the construction of the project, Samsung C&T intends to actively participate in penetrating the Qatar market and plans to strengthen its ability to become a major player in the global civil infrastructure business. Qatar is expected to spend USD 80 to 100bn over the next five years to prepare and deliver the infrastructure needed to host the 2022 Fifa World Cup."

The Lusail Development Site is located 22km north of the Qatari capital, Doha.

HONG KONG, CHINA

Aecom has been awarded a USD 148M consultancy contract for the Tuen Mun-Chek Lap Kok Link (TM-CLKL). The link forms part of the Hong Kong-Zhuhai-Macao bridge-tunnel (HKZMB) megaproject.

The contract covered detailed design, supervision, reference design and contract administrative responsibilities. An Aecom spokesman said, "[The link] will provide the most direct route between Hong Kong's Northwest New Territories, the Hong Kong Boundary Crossing Facilities of the HKZMB project, the Hong Kong International Airport and Lantau Island.

"The project works comprise a dual two-lane highway approximately 6 miles (9.7km) long, of which 3 miles (4.8km) are in the form of a sub-sea tunnel, and is expected to be completed at some point during 2017."

Aecom chairman and CEO John Dionisio added, "This is the second design and construction consultancy that we have won for Hong Kong-Zhuhai-Macao Bridge related projects.

"We are honored to partner with Hong Kong's Highways Department to play a key role in its continuing development of Hong Kong's transportation infrastructure."

ASHBURTON NORTH, AUSTRALIA

Thiess will execute the Wheatstone Project in Western Australia. The AUD 60M (USD 62.1M) contract was awarded on 22 December for a 1.2km-long LNG pipeline tunnel.

The drive will connect to client Chevron's Wheatstone and Lago reserves. A 1.1m pipeline will be jacked with a 2.5m microtunnelling cutterhead. Engineering and procurement began in December following the announcement to design the TBM launch shaft, jacking pipes and retrieval pit. Construction will begin 'following the 2013 cyclone season' (season typically runs mid February to early March).

Managing director of Thiess, Bruce Munro, said, "Thiess already has a major role with Chevron in delivering its Gorgon LNG project and we're delighted to further our participation."

MELBOURNE, AUSTRALIA

Jacobs Associates announced last week that the last shaft cover had been lowered into place on the Northern Sewerage Project in Melbourne, Australia. The event marked the end of the five-year, AUD 650M (USD 663.6M) project, which began in August 2007 and was completed six months ahead of schedule. It was AUD 135M (USD 137.8M) under budget.

John Holland was contractor, Aurecon was project manager and Jacobs was the designer with Sinclair Knight Merz.

A Jacobs spokesman said, "Most construction work for the new sewer took place between 15 and 64 meters underground. A 3m-diameter hard rock TBM and two EPBMs (4m and 3m) were used to construct seven tunnels through a variety of ground conditions ranging from basalt to weak, interbedded siltstone and sandstone.

Unmapped motorway tunnel penetrated by drill

SWEDEN

A geotechnical investigation drill penetrated a traffic tunnel in Stockholm last month. The Stockholm police force could treat the accident at the 4.7km-long 'Southern Link' motorway tunnel as a criminal offence, an act of negligence or a case of endangering the public.

Coach driver Gunnar Norberg was driving through the tunnel when an iron bar sliced through his windscreen after falling from the tunnel roof. Norberg told local radio: "Suddenly there was a bang and the whole windscreen just vanished. I went outside, only to see this huge iron bar that came through the ceiling and went all the way into the ground. It was quite obvious that someone was drilling above."

Norberg added, "You could hear that it was someone drilling. There was a bloody racket down there in the tunnel. And they kept on drilling, obviously unaware of what had happened."

A spokesman for a Stockholm Traffic Management Centre said that a company gathering data for a potential building project had simply drilled in the wrong place. Reportedly the drill penetrated the tunnel and a pipe fell down, hitting the vehicle.

The workman carrying out the drilling told the same local radio station that the tunnel was omitted from the maps given to him by the city council. He added that he heard on the radio that traffic had been halted, but the fact that he was responsible did not occur to him until the police arrived on site.

Limited traffic access was later granted after an inspector checked the damages. No one was hurt despite two trucks crashing.

Airdrie TBM extracted

GREAT BRITAIN

The Airdrie stormwater sewer TBM was last month hauled from its reception shaft after completing a 1.2km tunnel in Lanarkshire, Scotland.

The tunnel is 2.44m internal diameter and runs up to 40m below ground in places. Excavation was concluded in late December 2011.

The tunnel will divert flows caused by heavy rain into a new storm tank near the old Airdrie sewage works. The project will improve water quality and reduce the risk of flooding.

A spokesman for client Scottish Water said, "This is one of the largest projects that Scottish Water is doing in Scotland in the 2010-2015 investment period."

Scottish Water project manager Brian Dalton said, "In the coming months our other TBM will be creating smaller tunnels under the area around the railway station and adjoining streets. These will connect the new storm transfer sewer to the local network."

He added, "This work has been agreed with North Lanarkshire Council and is due to be completed by March 2012."

Breakthrough on the 1.2km sewer tunnel

Urban CSO jack in Jersey

GREAT BRITAIN

Donaldson Associates will provide detailed design work for a 'challenging' 65m underground connection. The 1.2m-diameter pipejack will make the connection to the Surface Water Link tunnel in St Helier, Jersey, from a 7m-diameter secant piled shaft.

A new combined sewer overflow below the street level will be constructed to divert surface water into one pipejack, and foul sewage into another. The client is the Transportation and Technical Services Department of the States of Jersey.

A Donaldson Associates spokesman said, "Particular challenges include ensuring that the works do not draw down groundwater from the superficial deposits and thus cause settlement to historic buildings build on raft foundations."

News in brief

Engineers Ireland recognises Portlaoise
The Portlaoise Main Drainage scheme in County Laois, Ireland, has been voted Environmental Infrastructure Project of the Year in the 2011 Engineers Ireland Excellence Awards. The scheme was delivered by RPS (consulting engineers), Murphy International (contractor for more than 17km of pipeline construction) and an Aecom – Bowen JV (for the wastewater treatment plant) for Laois County Council.

Airport TBMs burial to be discussed
Members of the Queensland ATS Group and visitors are invited to attend a Technical Session on 9 February about "The Burial of the Airport Link TBMs." Twin 12.45m diameter EPBMs were used on the project and each 1,270t shield was buried under the alignment, in pits 16m deep, within three weeks of final breakthrough. More information is available from Engineers Australia.

Call for safety awards
The British Safety Council's International Safety Awards 2012 scheme is now open for applications. This scheme recognises the commitment of organisations, in all sectors and across the globe. The awards relate to individual sites and business units allowing organisations to enter as many sites or business units as they wish. The detailed marking scheme is available to all applicants and sets out the scores that have to be achieved in order to gain a pass, merit and distinction. Last year there were 602 applications, 90 per cent of which were successful. Details of the awards scheme are at https://www.britsafe.org/

Oberosler and Edilmac team take on Italian hydropower project

ITALY

The raiseboring team of Edilmac last month began work on a project for contractor, Oberosler on the Mulbach Rio Pusteria hydropower scheme, in Bolzano, South Tyrol, Italy.

Work involves two 431m-deep, vertical penstock shafts, one 1.84m in diameter and the other 1.55m. The RVDS (Rotary Vertical Drilling System) will be used for the pilot hole through granite before reaming. The automatic RVDS has been developed by Germany's Micon Mining & Construction Products with current tool diameters of 9.5in. (241mm) to 12.875in. (327mm).

It follows successful work on the Laives Tunnel in 2011.

On the Laives Tunnel, Edilmac and Oberosler were among other partners in the Laives Tunnel consortium, which has been building a new road tunnel for the Province of Bolzano on the SS12 route. Here Edilmac sank a vertical ventilation shaft 280m deep and 4.74m in diameter. The geological conditions were difficult, including porphyry formation.

First the pilot hole was bored using Edilmac's Atlas Copco Robbins 83, and then reamed to its full diameter using a Herrenknecht 550VF.

On completion of the excavation the shaft was lined from a platform supported from a bridge crane over the shaft, which was also used to transport the materials and equipment. The gantry crane also carried a winch to lift operatives through the shaft.

The RVDS operates using steering produced by expandable stabiliser ribs with inclination monitoring using two accelerometers.

The monitoring data is handled with full digital, downhole, closed-loop control and transmission to the surface by mud pulse.


The tunnel project is underway in Italy

Crossrail award spoil removal contract

GREAT BRITAIN

A JV of Bam Nuttall and Van Oord UK will transport excavated material from the Crossrail sites to Wallasea Island, Essex, UK. The spoil will be used to create a nature reserve for UK wildlife charity, Royal Society for the Protection of Birds (RSPB).

Some 4.5Mt of material will be sent to the site from Instone Wharf in up to five ships per day starting in summer. Tunnelling will begin at the Royal Oak portal in March.

Crossrail programme director, Andy Mitchell, said: "We are delighted to be working in partnership with RSPB to create a major new nature reserve that can be enjoyed for generations to come. At least two-thirds of all Crossrail excavated material will be used to create the wetland at Wallasea Island."

This is the last remaining major Crossrail contract to be awarded that will allow tunnelling to commence in spring 2012.

Caterpillar boosts China R&D base

CHINA

Caterpillar has announced further investment in its Chinese research and development centre. Based in Wuxi, Jiangsu Province, Caterpillar's R&D centre opened in December 2009 and employs more than 500 engineers.

Caterpillar vice president and chief technology officer, Tana Utley, said, "China is the largest construction equipment market in the world, and Caterpillar continues to invest in China to help our Chinese customers succeed and to position Caterpillar for long-term leadership in China.

"The Wuxi R&D center is enabling Caterpillar's product development success in China and other growth markets."

The facility is located close to Caterpillar's component factory, which began production in 2006. The company's flagship excavator manufacturing facility is located in nearby Xuzhou, also in Jiangsu.

New underground River Thames crossing announced for London

GREAT BRITAIN

A new tunnel for crossing will be built under the River Thames in London, UK, within a decade said the city's mayor on 23 January.

Boris Johnson revealed the proposed link between Greenwich Peninsula and Silvertown in the Royal Docks in a speech to 'London's Government leaders'.

Transport for London will begin preliminary consultation on the project in February. The crossing will have a flow capacity of almost 2,400 vehicles per hour.

Prior to his speech to the leaders, Johnson said, "When I look at London I see a city of incredible potential and tonight I will make the case for a huge new phase of investment in the capital, including a major new river crossing east of Tower Bridge.

"We are in the right time zone, speak the right language and have the young, skilled population to continue to attract investment from the world's greatest businesses."

He added, "This is not a time for London to falter it is a time for London to flourish."

John Biggs, a Labour member of the London Assembly, representing the City and the east, said, "One of Boris Johnson's first moves when he came to power was to scrap plans for a new bridge in east London and throw away its funding to the tune of hundreds of millions.

"We've now been waiting almost four years. If he hadn't been so short-sighted back in 2008, we could have been opening a river crossing now. Instead, all we have is a tunnel that is years away and doesn't appear to have any funding behind it."

Liberal Democrat London Assembly member and chair of the London Assembly Transport Committee, Caroline Pidgeon, said the crossing was desperately needed, but funding is an issue. "The last thing we need is pre-election promises from the Mayor of London that turn into nothing."

Jaiprakesh chairman to appeal insider trading decision

INDIA

India-based Jaiprakesh Associates chairman and CEO, Shri Manoj Gaur said he will appeal against the Securities and Exchange Board of India's (SEBI) decision to fine him, his wife and his brother for violation of insider trading regulations.

SEBI has fined each Manoj Gaur, his wife and his brother INR 1M (USD 18,986) for purchasing shares using unpublished, price-sensitive information.

The order of the adjudicating officer, posted on the SEBI website on 5 January was in judgement of 8,400 shares purchased by Manoj Gaur's wife and brother between 13 and 16 October 2008.

Manoj Gaur said the purchases were not made based on any insider information and that the shares were never sold. He added, "The findings in the order are completely erroneous and contrary to factual position. It is unfortunate that despite adequate representation to the adjudicating officer, frivolous inferences have been drawn. Aggrieved by the order, we are in the process of challenging the same before the Securities Appellate Tribunal."

Atlas Copco acquires GIA Industri

SWEDEN

Atlas Copco announced on 16 December, that it had purchased Swedish underground manufacturer GIA Industri from Vatterledens Verkstad. The purchase price has not been disclosed to the public.

An Atlas Copco spokesman said it has added electric mine trucks, utility vehicles and ventilation systems to its range.

The 130-year-old GIA Industri business based in Grangesberg, Sweden had a complement of 113 employees at the time of acquisition. It boasted an annual revenue of approximately SEK 230M (USD 33.75M).

Other business areas unrelated to mining and underground construction were not sold.

"The acquisition of GIA is a good strategic fit for Atlas Copco," said Bob Fassl, president for Atlas Copco Mining and Rock Excavation Technique.

"We are entering new market segments and will be able to serve customers with an even broader product portfolio.

"We especially look forward to offering our customers the Kiruna Electric haulage truck with its strong environmental profile.

Rick Capka returns to Parsons Brinckerhoff

USA

Rick Capka was this month appointed to the Parsons Brinckerhoff (PB) Seattle office, US as area manager of construction services. His responsibilities will include the Alaskan Way Viaduct bored tunnel replacement.

A PB spokesman said, "Capka most recently served as a construction manager for Sound Transit, working on several underground construction contracts associated with the University Link light rail in Seattle. Prior to his employment with Sound Transit, he was a resident engineer for Parsons Brinckerhoff, working on the Beacon Hill tunnel and station of Sound Transit's Central Link light rail."

Capka studied at West Point Military Academy, has a degree in civil engineering and is a licensed professional engineer in the state.

...and is joined by Robert Stromsted out east

USA

Robert Stromsted is the newest senior vice president at Parsons Brinckerhoff (PB). Stromsted will be responsible for strategic planning and business development at the PB office in New York.

Prior to joining PB, he was CEO at HNTB Corporation, responsible for strategic oversight and the development and implementation of growth strategies for the firm. Stromsted attended Stanford University, and holds Eng and MSc degrees in civil engineering. He was formerly a Coast Guard officer and earned a BSc in civil engineering from the US Coast Guard Academy.

President of PB's US transportation arm, Gregory Kelly, said, "Stromsted brings a wealth of project, management and executive experience to our management team."

News in brief

Salini increases ownership of Impregilo
Italy-based Salini announced last month that it had exceeded the 10 per cent share threshold of Impregilo as of 16 December and 15 per cent on 20 December. Nearly 28M shares were bought between 5 October and 20 December. The total shares owned by Salini increased to approximately 60.5M.

National Grid extends alliances with firms
UK and US-based power distributor National Grid has agreed a second five-year term on two alliances with suppliers in the UK, which have been running since 2007. The alliances are the Electricity Alliance West with a joint venture of Mott MacDonald, Amec and Babcock Networks, and the South East Electricity Substation Alliance (SEESA) with a joint venture of Mott MacDonald, Alstom Grid and also Skanska.

Arup moves to larger New York office
Arup moved its New York presence to a new office on 17 January. The new office is at 77 Water Street, New York, NY, 10005. Tel: +1 212 896 3000. An Arup spokesman said that growth led to the decision in 2010 to expand.

Market growth makes for sales team expansion
German mining and tunnelling machinery manufacturer PAUS announced the hire of sales manager Michael Schumann on 11 January. It also added Oliver Wilke to the sales team in November to cover Turkey, South Africa, South America and Australia. PAUS attributed the expansion to a "continuous high order volume" and rapid market development.

DSI Norway bought by Spennteknikk

NORWAY

Spennteknikk International acquired Dywidag Systems International (DSI) subsidiary, DSI Norway. The contract was signed on 23 December and became effective as of 2 January.

A DSI spokesman said, "Due to a highly fragmented market environment and today's competitive situation, DSI is expecting DSI Norway to not be able to realise future growth perspectives. After preselection of potential candidates, Spennteknikk International proved itself as the best partner for DSI due to complementary technologies and structures.

Redpath makes European expansion

CANADA

J.S. Redpath Holdings has announced its acauisition of Germany's Deilmann-Haniel Shaft Sinking, effective as of 1 January.

Deilmann-Haniel has a 120-year history of providing specialty-mining services to the European mining industries, focusing on ground freezing and the design and installation of complex shaft linings.

"The acquisition of Deilmann-Haniel is of great strategic importance to Redpath as it allows us to offer our services to our global mining clients throughout the world and provides a platform for growth in the European and Russian markets," said George Flumerfelt, president and CEO of the Redpath Group.

Redpath has offices in North and South America, Asia, Australia, Africa and now Europe.

Blastcrete names GM

USA

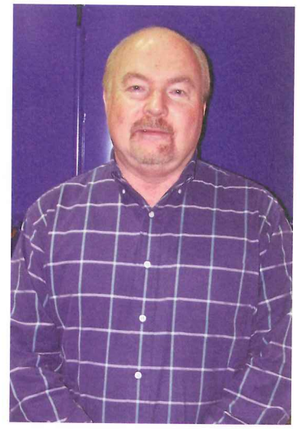
Blastcrete Equipment Company has announced the appointment of Maury Bagwell as general manager. In his new position, Bagwell's primary responsibilities are product development and engineering and management of employees.

He will also oversee quality control in his new position.

Bagwell has more than 20 years of experience in manufacturing, sales and product design and engineering. Prior to joining Blastcrete, he was involved in both engineering and sales for Engine Power Source as an OEM sales manager.

He has a background in mechanical engineering, and expertise in power transmission and hydraulic component design.

"I'm eager to build on the reputation Blastcrete has established as a trusted partner, delivering safe, dependable and effective equipment," he said.



Above: Maury Bagwell was announced as GM of Blastcrete Equipment Company

"It's my goal now to raise the bar even further by streamlining our processes, from the initial design and CAD drawing phase up to final production.

"Ultimately, it's going to result in greater efficiency and allow us to provide the best products and service for our customers."

Ahmadinejad promotes Iranian tunnellers on visit

IRAN

Iranian President Mahmoud Ahmadinejad was last month promoting Iranian tunnelling interests during a tour of South American countries Venezuela, Nicaragua, Cuba and Ecuador.

Iraj Milani, a deputy in charge of the Iranian Embassy in Colombia, said the tour was designed to boost bilateral trade and find new opportunities for Iranian construction companies that have expertise in tunnel and dam engineering works.

Iranian trade with the region has reportedly been surging and the country is setting up new embassies in the area. "Our government is simply trying to diversify its trading partners and promote more 'South-South' collaboration," said Milani.

Iran has already announced more than 200 joint industrial projects with Venezuela, according to US sources.

The visit coincided with rising tensions between the US and Iran.

News in brief

Robbins opens new office in South America
Robbins announced on 16 January operations in Santiago, Chile, to support the local tunneling market. Robbins South America will be led by managing director, Rolando Justa with support from project coordinator, Esther Zerrer.

Managing director change at Dehli Metro
Mangu Singh replaced Elattuvalapil Sreedharan as managing director for the Delhi Metro Rail Corporation DMRC as of 1 January. Sreedharan joined the DMRC in November 1997 as its first MD and is credited for changing the face of Indian public transport with his work in building the Konkan Railway and the Delhi Metro.

URS name change
The URS Scott Wilson name in the UK & Ireland, Europe and the Middle East has changed to URS as of January. URS says this is part of a global programme to have a single and consistent brand across the company's operations. URS aquired Scott Wilson Group in September 2010. In some regions, such as India and China, the brand's transition will be phased.

Jacobs associates adds Paroline in California
Shawn Paroline joined Jacobs Associates as a lead associate in the Claims Group. He is based in Southern California, working out of both the Pasadena and San Diego offices. He has more than 17 years of experience in construction and program management for public works infrastructure including complex water pipelines, pump stations, treatment plants and tunnels.

Breakthrough
at Lai Chi Kok main tunnel

Branch tunnel TBM assembly

Breakthrough was reached in December on the main section of the Lai Chi Kok Drainage Tunnel project in Hong Kong. Located in an urban area, sensitive structures that included railways, viaducts and culverts were of primary concern to the client, Hong Kong Special Administrative Region Drainage Services Department.

Contractor Leighton-John Holland JV employed a 5.7m Herrenknecht Mixshield slurry TBM to bore through bedrock 40m deep under high pressure to avoid surface disruption. Supervising consultancy was provided by Aecom who worked for nearly two years on planning and design work with the client.

Drainage Services Department director Chan Chi-chiu added, "We have overcome a number of challenges during the construction of the main tunnel including driving the TBM across four overlying operational railway lines and through the foundations of numerous existing infrastructures.

"Work involved 90 construction operations under hyperbaric pressure up to 4.2 bar, which is unprecedented in Hong Kong. We have taken this opportunity to bring new hyperbaric technology to Hong Kong."

The water table lies between 1 and 2m of existing ground level along the main tunnel alignment.

Aecom executive director Bob Frew explained the decision to opt for a TBM rather than traditional drill and blast. "The feasibility study proposed drill and blast with pre-injection grouting 80 to 100m below ground for the main tunnel. We believed a closed face TBM was more appropriate as it eliminated cost uncertainties and major construction risk. I think this was why we were the client's choice, because we did not offer the Hong Kong standard solution.

"The only unique aspect was the decision to locate the tunnel at a depth that required hyperbaric intervention at pressures above 50 psi (3.45 bar). It was a commonly held view that intervention above this pressure was inherently more hazardous," he said. This meant that special effort had to be made to demonstrate to the regulatory authority that the health outcome would be as good, if not better, than that under the decompression tables prescribed for work up to 50 psi (3.45 bar). "This placed additional burden on the contractor as the party responsible for obtaining approval but with the support of Aecom and the client, this was achieved," said Frew.

The project was also one of three Drainage Services Department projects where the use of a geotechnical baseline report (GBR) was considered. "The others were the Hong Kong West Drainage Tunnel and the Tsuen Wan Drainage Tunnel. The former didn't use one though both Lai Chi Kok and the latter did, and a major effort was put into the Lai Chi Kok GBR," said Frew.

The 4.9m internal diameter, combined 3.7km main and branch tunnel, along with associated shafts and adits, will intercept stormwater in West Kowloon and transfer it into Victoria Harbour. Flood control has historically been an important concern for West Kowloon. The new system will catch surface runoff at six locations. It will be able to cope with a one in 50-year flood.

The Lai Chi Kok branch tunnel was completed in February 2011. It took 11 months of construction. After this, construction on the main tunnel began upon arrival of a VMT navigation system for the TBMs.

Geology comprised granite rock with limited sections of shallow cover and mixed ground in the high level branch tunnel. Faults and intrusions of dyke rock were also present. In the main tunnel there were distinct sections of granite rock at launch and completely decomposed granite at recovery, with a section of mixed ground in between in an almost 1:1:1 split.

Rock along the alignment was predominantly very strong to extremely strong. The extremely abrasive granite was split between the medium-grained Kowloon Granite and coarse-grained Shatin Granite. The alignment was considered to be sub-parallel to 19 potential faults. The bedrock granite has an average unconfined compressive strength of 200MPa and a maximum value of 325MPa.

Ray Chan, deputy project manager for the contractor's detailed designer, Atkins, said, "Constructing tunnels beneath densely populated areas and a dry shaft right next to the harbour, with extreme earth and water pressure was a huge challenge."

The TBM was named after the 16th century figure, Dae Jang Geum. Allegedly the only female Royal Physician in Korean history.

Alex Conacher

Hollistic Helsinki

In tunnelling circles Finland is most famous for Helsinki's 'Underground Masterplan' of underground space use. But planning only gets you so far. Pekka Särkkä, board member of the Finnish Tunnelling Association gives an update on the major projects and challenges faced in the country

The Lansimetro (West Metro) (see feature, page 30) will be an extension of the existing Helsinki metro line to Matinkyla in the city of Espoo. This fully automated line is expected to be opened for traffic by the end of 2015. It will transport more than 100,000 passengers per day and is designed for a 100-year life span.

The automated metro traffic will run through two parallel 13.9km-long rock tunnels. In total, eight stations will be built in rock. Some 15 vertical shafts with emergency exits are designed to serve technical needs as well. The two metro tunnels will be connected at intervals of 100 to 150m with crosscuts for pressure equalisation, emergency connections, and maintenance work. Nine access tunnels will be made for construction and maintenance. The stations will be nearly 200m-long rock halls with a span of 23 to 25m.

The project requires the removal of around 1.6M solid cubic metres of rock. The tunnels and stations will be excavated by drill and blast, and reinforced with corrosion protected rock bolts and fibre-reinforced shotcrete.

The facilities will be located in hard bedrock composed of Precambrian granite and various kinds of gneisses. These contain zones with fractured rock, especially undersea and in the areas prone to settling, which from a tunnelling point of view will be challenging. The dimensions for the track tunnel are based on space requirements of the metro train and its rail system plus an additional 1,200mm for an emergency exit lane. In the parts where the tunnels cross the sea, free space to build a water-pressure-proofed construction is reserved in the excavation profile.

In the Keilaniemi district of Espoo, for example, four 100m-tall tower buildings are planned next to and above the metro line and station. The foundation pressure of the buildings is between 2 and 4MPa for each. Thus it has to be confirmed that these additional loads will not damage the tunnels and, on the other side, that the tunnels will not cause unacceptable displacements on the foundations above. Therefore, three-dimensional modelling is also required here.

A project plan on the West Metro extension from Matinkyla to Kivenlahti is currently in preparation. The length of the extension will be some 7 to 9km, containing six additional stations and a metro depot, all in rock spaces. The preliminary budget of the extension is some EUR 610M (USD 779.6M).

If everything goes smoothly, the extension works can be started in 2014 and it can be operative in 2020.

Above: **Excavation on the Lansimetro (West Metro) in Helsinki**

Ring Rail Line

The Ring Rail Line is an urban two-track passenger line for local traffic in Vantaa between Vantaankoski and Tikkurila and a rail link from Helsinki to Helsinki-Vantaa airport. The total length of the new line is 18km, of which 8km runs through twin tunnels mainly under the Helsinki-Vantaa airport area. Trains will operate on the Ring Rail Line at 10-minute intervals in both directions during peak periods. The maximum train speed will be 120km/h. Construction of the Ring Rail Line began in spring 2009 by drill and blast. The line will be open for traffic in the middle of 2014.

The tunnel system consists of four underground rail stations with access tunnels, pressure equalisation and smoke removal shafts, vertical exit shafts, connection tunnels at 200m intervals, rail exchange areas and heat transfer tunnels in portal areas. The geomechanical behaviour of all four underground stations is simulated using Three Dimensional Distinct Element Code (3DEC). Critical key blocks are analysed with Unwedge.

The aerodynamic simulations were carried out in two steps. Air speeds were found to reach up 7.5m/s for short periods. During regular operation the peak air speeds are approximately 6m/s. As regulations allow the air speeds to increase to a maximum of 10m/s in rare cases, the present design of the tunnel system is assessed to be acceptable.

Rapid Tampere

In Tampere, a design decision has been made on a twin-tube, twin-lane highway tunnel passing the downtown Tampere from east to west below Tammerkoski (Tampere rapids). The tunnel length will be about 2.3km and tunnel dimensions are about 15m by 8m each with a 11m wide pillar in between.

The tunnels will be connected by crosscuts with 200m intervals. The preliminary budget of the tunnel is some EUR 190M (USD 242.8M). If everything goes smoothly, the works can be started in 2013 and it can be operative in 2020.

Denmark's designs

Connecting mainland Europe and Scandinavia, Denmark is a key infrastructure link. Soren Eskesen, International Tunnelling Association vice president explores the latest plans and projects from his home nation

Although Denmark is a country without major mountains, it still has a large number of tunnels under construction and in planning, making for a busy tunnelling market. Denmark is a country consisting of several islands and with a central location connecting the rest of Scandinavia to mainland Europe. Urbanisation is developing particularly rapidly in the area of its capital, Copenhagen. These factors contribute to the need for having tunnels and underground structures constructed to develop the major cities and the connections to the neighbouring countries of Denmark. Further, there is a political will to strengthen the public transport with upgrading of the railway network, introduction of light railways and extension of the Copenhagen Metro systems.

International connections

The Fehmarnbelt Link connecting Germany and Denmark is in planning with construction expected to run from 2014 to 2020. It will consist of an immersed tunnel 18km in length carrying a four lane motorway, and a double track railway will connect the Danish island Lolland with the German island Fehmarn. The project will be tendered in 2013.

The Helsingborg link under the Oresund has been considered for more than 50 years but is still in the early study phases. The project is becoming more and more necessary as the railway capacity on the present Oresund link is almost exhausted and more traffic can be expected when the Fehmarn link opens. The Swedish parliament has decided to give priority to the project and has included it in the national infrastructure investment plan. The government has suggested a link with two alignments one for passenger trains and another one for freight trains and cars.

Metro

Due for completion in 2018, Copenhagen´s new metro circle line, Cityringen, (see feature page 24) with its 17 underground stations, will all be interconnected by 17km of twin bore tunnels. This project links central districts of the inner city into an increasingly integrated transport network. The two major contracts for the Cityringen project were awarded on 7 January 2011; a single design and build contact for all the civil works and a transportation systems contract for rolling stock and the control and maintenance centre.

Provisions are made for future extensions by having bifurcations chamber construction for two new metro lines: the North Harbour and the South Harbour lines.

Railway and roads

In Copenhagen the North Harbour Road (Nordhavnsvejen) is under construction. It consists of a four-lane road connecting the Helsingor Motorway with the Northern harbour. It is 1,650m long of which 620m is in a cut and cover tunnel undercutting an existing railway line and a major road. It is scheduled for completion in 2015.

In Denmark's second major city, Aarhusa, a similar project, the Marselis Boulevard Tunnel, is under construction. The first phase, connecting the motorway system and ring road network with the Port of Aarhus, is under construction. The second phase with a 2km cut and cover tunnel is delayed due to financial problems.

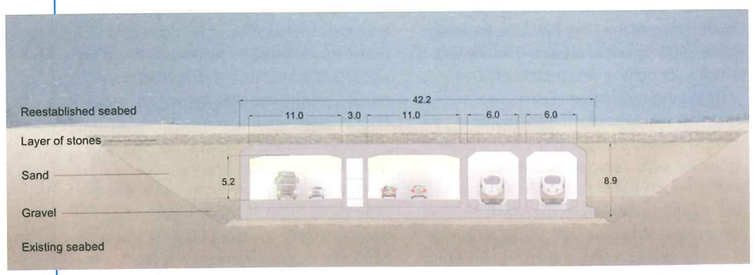
The new railway between Copenhagen and Ringsted, which will follow a new alignment will include four tunnels of a total length of 1,750m. The construction work is expected to start late 2012 and be completed by 2018.

Longer perspective

Different alignment studies have been carried out for a new eastern bypass around Copenhagen. In February 2009 the Danish Government presented its plan for the Danish Transport Policy until 2020. The plan states that the government will initiate a strategy analysis for the eastern bypass. In the longer perspective, tunnels are being considered for crossing the belt between Jutland and Funen, and tunnels to connect the island of Zealand with Jutland with four or six lane motorways and railways.

Tunnels are also being looked at to deal with drainage water from heavy rainfall. So far utility tunnels have not been so common in Denmark, however the first major utility tunnel with a 4m diameter has been brought into operation and more may follow.

Additionally, Copenhagen residents are calling for more metro lines; it is therefore thought that the tunnelling market will continue to grow and interesting jobs working with tunnels and underground structures will increase in the future.



Left: The Fehmarnbelt Link connecting Denmark and Germany

Sweden on song

Håkan Stille professor emeritus in soil and rock mechanics at the Royal Institute of Technology (KTH), digs into what drives the Swedish tunnelling industry

The last decade has been a good period for the Swedish tunnelling industry and tunnels have been constructed for many purposes both in Sweden and abroad.

The Swedish mining industry, which mainly requires underground excavations, has exploited greater depths with an increased need for permanent tunnels. New and deeper mining levels are planned with increasing rock mechanic challenges. The rock stresses increase with depth. Rock burst due to large-scale instability has been observed more frequently. Rock support to stand both high static rock stresses and dynamic stresses from blasting and rock burst are two issues that are studied at our universities in order to facilitate deep mining. The deeper mining activities of LKAB (an iron mineral producer) mean that part of the Kiruna City in the northern extremity of Sweden has to be moved. Planning and preparation work has started. It is anticipated that the city will have to be moved gradually during the next 20 years.

Power thirst

Another and increasing market for tunnelling is the energy sector. Many of our hydropower plants are old and have to be renovated. This will involve changes but also installation of further turbines and enlarging the waterways. This type of tunnelling work always involves careful blasting and intricate excavation in order not to damage the installations. It is thought that this type of work will increase in the coming years.

Building storage for nuclear waste will belong to this energy sector. The nuclear waste management company in Sweden, SKB, has applied to the authorities to build underground storage in Forsmark north of Stockholm. The storage will be situated in Precambrian granitic rock at a depth of 500m and up to 60km of tunnels will be excavated. The design work has already started and it is anticipated that the excavation works will start in 2017.

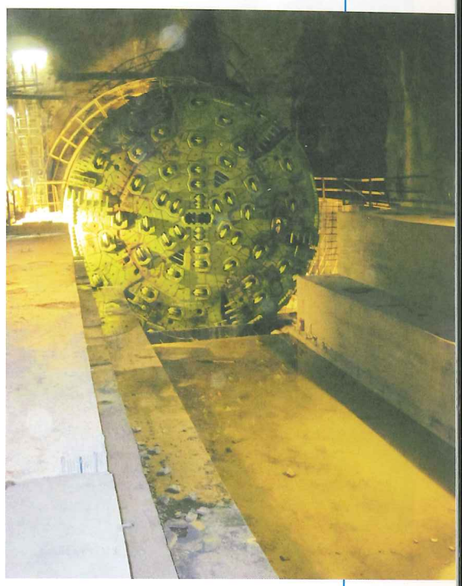
Rail and road demand

Many tunnels for railways and roads have been constructed the last 10 years, and new projects are planned especially in major cities like Gothenburg and Stockholm. The Northern Link of the ring road around Stockholm is under construction in the northern part of the city. In total 11km of tunnels with motorway standard will be opened by 2015.

The Citybanan project under the centre of Stockholm is a railway tunnel with two major underground stations close to existing metro lines and other tunnels. The work is ongoing. There has been a special focus from the authorities and contractors on developing pregrouting technologies in cooperation with the Swedish Technical Universities. Normally, Swedish tunnels are only supported with rock dowels and a thin shotcrete lining. The waterproofing requirements are strict and the allowable ingress of water is in the order of one to 4 litres/min in 100m of tunnel. Pregrouting is one alternative and the other is constructing fully concrete lined tunnels that should withstand the ground water pressure. Pregrouting has so far been a competitive solution compared to the lined alternative.

Hallandsas

The 8.7km long railway tunnel through Hallandsas in the southern part of Sweden is ongoing. The project has met many problems with very severe water ingress and environmental disturbances due to chemical grouting. The geology is a very fractured and water bearing horst. One of the two railways tubes is now complete. It has passed through a 50m wide zone of completely decomposed rock situated 140m below ground water level. In order to pass through with the TBM, the silty zone had to be frozen. The TBM has been reconstructed before excavation of the second tube. Progress is very good and better than planned. As *T&TI* went to press, 79 per cent of tunnel work is complete. The tunnel is planned to be open to traffic in 2015.



Above: A TBM mining the Hallandsas railway tunnel.

Inbound interest

The good market has encouraged contractors from central Europe to open branch offices in Sweden. Scandinavian contractors such as NCC, Veidekke, Lemminkainen and Skanska have to compete with foreign companies such as Bilfinger Berger, Beton and Monierbau, Hochtief, Strabag, Zublin and Pihl & Son. It has in many aspects vitalised the market and the development of new technology.

The Swedish Rock Mechanic Society is hosting the Eurock conference in May. This is achance to visit Stockholm and its tunnel projects when the city is at its best.

Norwegian network

A decade of growth for Norway has seen the industry boom in all sectors. This overview is presented by Thor Skjeggedal, secretary general of the Norwegian Tunnelling Society, Steinar Livik, project manager at The Norwegian Public Roads Administration, Anne Kathrine Kalager, project director at The Norwegian Railway Authority and Ola Woldmo, secretary of the Norwegian Tunnelling Network (NTN)

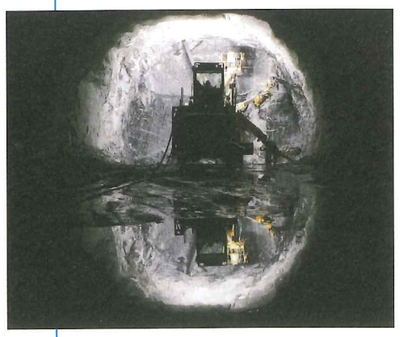
The prospects for the New Year are good. Statistics covering 2011 underline continued increasing underground activities in line with the trend of the last 10 years, both in volume and revenues. Tunnelling in Norway is closely connected to five areas: roads, rail, hydro, oil and mining.

Norway is a mountainous country with deep fjords and adverse topography in considering efficient infrastructure. It is, on the other hand, rich in natural resources. Without going into politics it must be mentioned that, for better or worse, new projects and their financing gets decided by parliament more or less on a yearly basis.

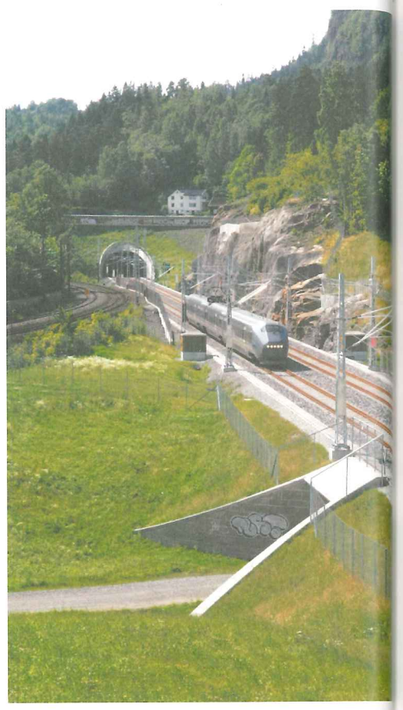
Better roads are needed and road construction is dominating the tunnelling market. The construction of subsea tunnels started far north with the 2,890m-long Vardo tunnel in 1982. Since then 30 projects have been implemented crossing fjords and straits. The longest so far is the 7,920m-long Bomlafjord. Eiksund is the deepest at 287m below sea level. Plans for Ryfast and Rogfast ('fast' is Norwegian for 'fixed connection') are more ambitious and will certainly be implemented during the next few years. Ryfast, is impressive with its 14.1km Hundvag tunnel and Rogfast will be a leader with a length of 25km and a depth of 360m below sea level. Construction of motorways in central areas has in the past been neglected, and today several are under construction including numerous tunnels. In 2011 some 30 road tunnel projects were handled by the authorities and the list of upcoming projects is long.

Construction activities for improving the railway system are underway. In the southeastern part of the country this involves inter-city from Oslo to Halden, from Oslo to Lillehammer and from Oslo southbound on the western side of the Oslo fjord. These projects include numerous tunnels. The longest one starts at Oslo Central Station and runs to Ski. The two parallel tunnels each 19.6km long may lead to a TBM revival in Norway.

Hydropower development had its peak period up to the end of the 1980s. Environmentalists have opposed further development. However, during the last decade several projects were implemented regardless. Sauda, a full project with underground powerhouse and long tunnels was finished in 2011; as *T&TI* goes to press, Brokke in the southern part of the country is out for tendering.



Left: Excavations for an underground project in Norway



Above: Rail is one five main demands for tunnelling in Norway

For storage caverns one must look to Odda on the west coast and the mining industry. Caverns for waste storing are under construction. Finally to be mentioned are the increasing underground activities in the iron ore mining.

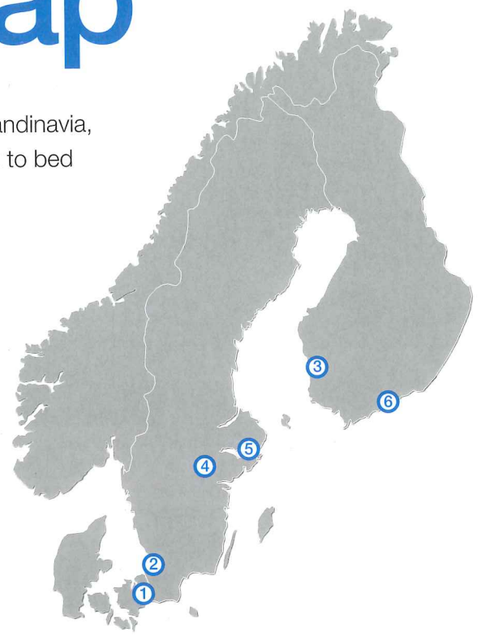
Norwegian contractors and suppliers in general have their focus on the home market, Some act differently. The Norwegian Tunnelling Network (NTN), a cluster of specialist suppliers, was established to provide commercial services to international clients and customers. NTN is a business network established by members of the Norwegian Tunnelling Society (NFF), the professional association of the rock blasting and tunnelling industry of Norway.

NTN is a network of companies and major stakeholders within NFF, and represents public clients, science and research institutions, education, engineering and design, consultants, contractors and suppliers.

The main focus is on the underground markets in South East Asia and NTN members are currently involved in major infrastructure projects in Hong Kong, Singapore and India among other countries and regions.

Scandinavian project map

A selection of important points from key projects in Scandinavia, from planned dream schemes to juggernauts finally put to bed



1 Copenhagen Cityringen (Copenhagen, Denmark)
- Civil engineering contract value of USD 1.98bn
- Contract awarded January 2011
- Some 15.5km of twin-bore tunnels, 17 stations, three shafts
- Four Seli-Kawasaki TBMs 5.78m, in the joint-first order for the JV along with the Bangalore metro
- Geology consists of a quarternary sequence of meltwater sands and tills resting on danian limestone
- Due to enter service in 2018

2 Hallandsas (Hallandsas horst, Sweden)
- East tunnel 5.5km by TBM, west 5.4km, 9.04m inside diameter
- East tunnel breakthrough in 2010, 18 years after start of tunnelling. The west tunnel has approximately two years remaining
- Soft, clayey rock encountered
- High water inflow experienced, up to 400 litres/s at 13 bar
- Multiple TBM types attempted
- 130m ground freezing in one section

3 Onkalo (Eurajoki, Finland)
- Nuclear material final disposal facility
- Full construction license application to be submitted in 2012, disposal scheduled to begin in 2020
- Construction began in 2004 with research in tandem
- Drill and blast excavation at a rate of 25m/week, with three shifts over five working days
- A 438m-deep access tunnel built as well as two demonstration tunnels (50m and 120m), from which final disposal canister testing holes (8m-deep x 1.8m-diameter) will be drilled.
- All shafts raise-bored

4 SKB's storage facility at Forsmark Nuclear Power Plant (Soderviken, Sweden)
- Nuclear material final disposal facility, site selected in 2009 following 20-year search
- License application submitted spring 2011, decision to be made in 2014 with construction in 2025
- Completion by around 2070
- Approximate depth of 500m
- Storage capacity 12,000t

5 Stockholm Citybanan (Stockholm, Sweden)
- A 6km twin-track tunnel as well as two major stations near existing works
- Project value of SEK 16.8bn (USD 2.44bn) at 2007 prices
- Stability, water ingress and environmental restrictions very high. Ingress limit of 1 to 4l/100m/minute
- A Special focus with Swedish Technical Universities on pregrouting, unusual for Sweden where tunnels are usually only supported with rock dowels and a thin shotcrete lining
- Will enter service in 2017

6 Helsinki West Metro Expansion (Helsinki, Finland)
- A 14km route, entirely underground
- Project value of USD 929.2M
- Two single track running tunnels, fifteen ventilation shafts, nine access shafts and seven new stations
- Entering service in autumn 2014
- Variable rock, generally very good but with significantly fissured local failures draining ground water and sometimes containing sedimentary intercalations
- Overburden ranges from 15 to 35m

Expansion of the Copenhagen Metro

Denmark's capital expands its metro system by two-thirds with its new ring line, the Cityringen. This report is presented by Sergio Notarianni of contracting JV Copenhagen Metro Team, Valerio Violo of Seli, Simon Taylor of client Metroselskabet and Soren Degn Eskesen, also of Metroselskabet

The Cityringen project comprises an underground metro system within the urban centre of Copenhagen, Denmark. The EUR 1.54bn (USD 1.98bn) metro civil works contract was awarded in January 2011 and the main civil works construction started in the summer of 2011. The civil works contract comprises 15.5km of twin-bore tunnels, 17 stations and three shaft structures.

Copenhagen is the capital of Denmark with a population of approximately one million inhabitants. In 2002 the first metro line was inaugurated and is a driverless, fully-automated system operating 24/7. The system currently in operation is 23km-long with 8km being underground along with nine of its 22 stations.

The Cityringen concept is basically 'more of the same' and follows two years of feasibility studies that formed the basis for the required political project endorsement. The Cityringen Act was passed in 2007 opening up the way for realization of the project. Metroselskabet is the company responsible for the operation of the existing Metro and the construction of Cityringen and is made up

Left: Figure 1, map of future Cityringen Line in Copenhagen; Below: Figure 2, Copenhagen in Denmark

Photo: Andrei Nekrassov / Shutterstock.com

the Municipality of Copenhagen (50 per cent), the Danish State (41.7 per cent) and the Municipality of Frederiksberg (8.3 per cent).

Cityringen, during operation, is expected to have 75 million passengers per year with around 240,000 passengers on weekdays. In 2011, the existing metro carried more than 54 million passengers in the year.

Ground conditions

The ground conditions along the alignment of Cityringen comprise a quaternary sequence of meltwater sands and tills resting on Danian limestone. The quaternary deposits are overlain by fill as well as post- and late-glacial deposits. Deposits belonging to the Selandian (Middle Palaeocene) Greensand Formation are also found locally subjacent to the quaternary deposits.

The fill layer is of varying size, with thick deposits found in areas with previous moats, lakes and canals, as well as old clay pits and sand/gravel quarries.

In the quaternary deposits two layers of till are observed, an upper till unit and a lower till unit, separated by meltwater sediments. Locally the two till layers constitute a contiguous layer, as seen in the Frederiksberg area. The tills are typically heavily over-consolidated, very stiff to hard sandy clays.

Three meltwater layers have been identified. The upper meltwater unit is of very limited extent, the middle meltwater unit is separating the two till units and the lower meltwater unit is mainly observed as coarse grained sediments filling erosion valleys in the project area.

Across much of the alignment the quaternary sediments are directly underlain by the Copenhagen limestone of Danian age. However, Selandian Greensand deposits are observed locally adjacent to quaternary deposits within the southern part of the alignment.

The Copenhagen limestone is a fractured soft rock that has some similarities to fractured chalk. Based on geophysical logging, the Copenhagen limestone has been subdivided into three sub-units, upper, middle and lower. The upper Copenhagen limestone is horizontally bedded with layers of different hardness and thickness from a few centimeters up to 1m. Flint occurs in beds of 0.2 to 0.4m thicknesses, occasionally up to 1m in thickness and can be followed continuously over long distances.

The pre-quaternary surface is characterised by meltwater erosion valleys, incised in the limestone surface. The interface between the quaternary deposits and Copenhagen limestone takes one of two forms, either more fractured than lower in the limestone (glacially disturbed) or unaffected by glacial disturbance.

The geological conditions that will be encountered by the TBMs will vary along the alignment. The tunnelling in the southern section is predominantly in the limestone, whereas the northern alignment is in glacial deposits, limestone and mixed conditions giving more difficult tunnelling conditions. It should also be noted that although the tunnels in the southern half of the alignment are generally in limestone, often the tunnels rise as they approach or leave the stations. In several cases the tunnel next to the stations are bored within mixed face deposits with corresponding larger amounts of ground movements. This is the case for instance close to Kongens Nytorv, Radhuspladsen and Kobenhavn H.

Groundwater control – dewatering and recharge

Each of the 20 deep constructions along Cityringen will be built below the groundwater table and will extend into the primary aquifer of the Copenhagen Limestone in the southern part between Aksel Mollers Have and Kongens Nytorv and limestone including sand and gravel in hydraulic contract with the limestone in the northern part of the alignment from Kongens Nytorv to Aksel Mollers Have.

Dewatering of groundwater inside the construction is necessary to build these constructions under dry working conditions. The location of underground structures in an urban area often requires that the abstracted water is recharged to the aquifer to maintain a normal ground water head outside the construction zones. This may be necessary to prevent settlement of buildings, control of contamination and deterioration of drinking water resources. The groundwater head will be monitored outside the excavation with sounding pipes in different layers to make sure that there is no lowering of the groundwater head out side the construction. Extending the depth of retaining cut off walls or grouting the bottom of the construction are two possible

mitigation measures that can reduce the abstraction and recharge rates, and thereby limit the risk of negative influence on the surroundings.

TBM selection

During the TBM design phase, it was very important to consider that the TBMs will be mainly driven in the limestone but also in soft ground. The alignment requires difficult sections in tills, gravel, with possibility of boulders and mixed face conditions. These sections could be difficult to cope with using a full-rock cutter head and, generally, more delicate passages occur with low over-burden and often under buildings.

Another factor that had to be considered in designing the TBMs is the long total stretch to be excavated with each machine, approximately 8.5km, which is significant in an EPBM project. The geometry of the TBM was driven by the tunnel diameter and, due to the small radius curves (190m minimum), the choice of double active/passive articulation was a natural one.

Within the tight geometrical constraints, the TBM offers important technical solutions, aiming to improve safety during excavation, efficiency and capabilities to cope with the changing geology.

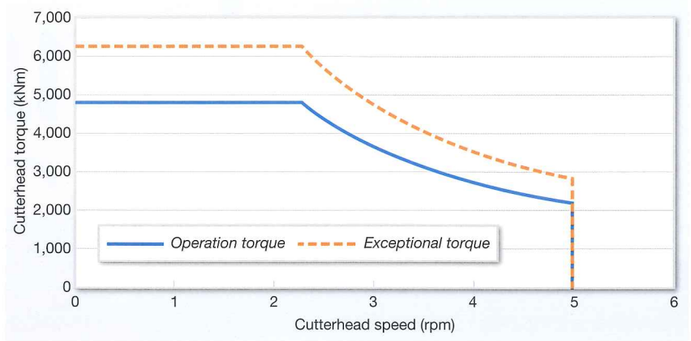
The four TBMs are designed and manufactured by the Seli-Kawasaki joint venture with a 5.78m excavation diameter. The shield is 10.5m long and the back-up is 80m long, thus relatively compact to facilitate TBM erection/dismantling phases and launching. The machines are equipped with six 200kW electric motors, for a total installed power of 1,200kW.

The TBMs are electrically driven. This was a natural choice to improve efficiency especially in the long stretches excavated in rock. The variable frequency drive (VFD) motors always supply the required power and torque and the torque curve is extremely efficient compared to a hydraulically powered machine. In Figure 3, above, it can be seen that the maximum torque is available immediately and is constantly supplied up to 2.3rpm, where the curve decrease starts, while the corresponding hydraulic machine will experience the torque rapidly decreasing as the rotational speed of the cutterhead increases.

The downside of the electrically-driven TBM is the space constraint: the challenge has been to fit the long motors into the shield and this has demanded enormous effort during the TBM design.

The cutterhead has been designed mainly for excavation in sound limestone, with the possibility of encountering bands of hard flint that can occasionally be massive. For this reason, the cutterhead accommodates 38 17-inch disc cutters with 267kN of individual maximum load. The shape of the cutter housing has been re-worked in order to maintain an opening ratio of 30 per cent which was the initial target based on the difficult passages in soft ground. The cutterhead is also equipped with a PLC controlled copy-cutter. If necessary, the disc cutters can be substituted with ripper tools.

Special attention has been paid to features for control of over excavation and reduction of settlement. The shield is not tapered and this leads to a lower over-excavation beyond the shield, thus reducing the ratio of settlement that can occur over the shield.



Above: **Figure 3, Torque vs. Speed curve showing maximum torque available immediately and constantly supplied up to 2.3rpm**

Table 1: TBM main characteristics

Main drive	
VFD electric motor	6
Total installed power	1,200kW
Speed	0-5rpm
Maximum torque	4,790kNm at 2.3rpm
Minimum torque	2,180kNm at 5rpm
Unlocking torque	6,237kNm
Cutterhead	
Excavation diameter	5,780mm
Opening ratio	30 per cent
Cutting tools	38 17-inch cutters
Maximum individual load	267kN
Copy cutter	Up to 5,880mm
(Wear detection system equipped)	
Thrust system	
Thrust rams	32 (16 by 2)
Maximum working thrust	37,000kN
Maximum total thrust	54,500kN
Articulations	
Front active articulation	30,000kN
Rear passive articulation	10,000kN

Annular grouting is a two-component system. This fast-setting grout leads to better bedding of the segments, better TBM steering and, last but not least, lower long term settlement development. An automatic face support (AFS) system is also provided, which is completely independent of the TBM operator and allows betonies injection to the cutterhead chamber in case the pressure drops below a predetermined value. The same system can also be used to keep the pressure constant during weekends or long stoppages.

The four TBMs are split into two pairs, with 'Pair A' excavating mainly the southern part of the alignment and 'Pair B' the northern section. The two TBMs making up Pair A will be lifted up and transferred twice while Pair B will only be transferred once.

General station concept

The station concept is a development of the deep stations on the existing metro lines and in most cases, follows the existing station design as far as possible, but each is modified as necessary to suit local conditions. Essentially, the station structures are built as cut and cover structures.

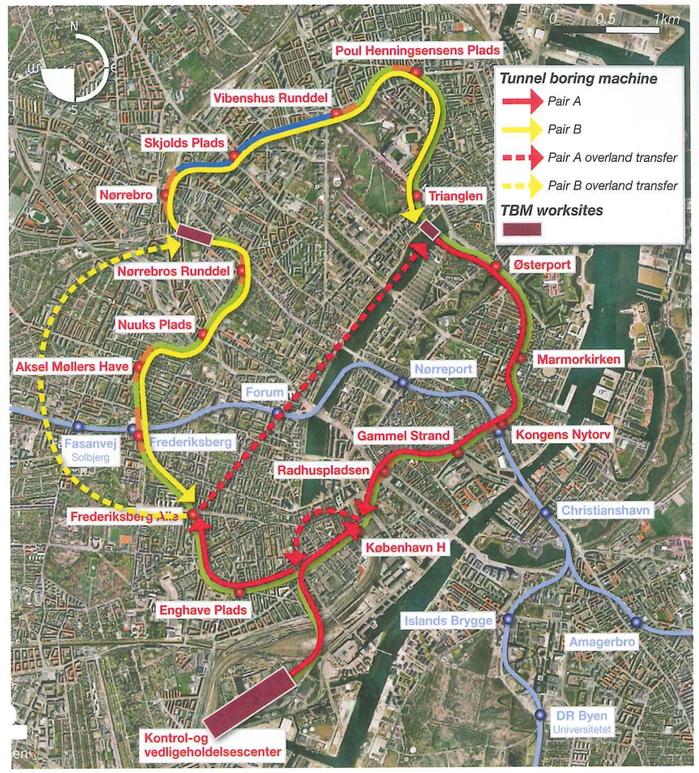
Under the design and build contract Metroselskabet, as the owner, has fixed the station positions and orientations, together with the platform levels, concourse levels and other main geometry. It was required that the stations have island platforms.

The basic concept for the deep stations is that they are in an underground rectangular box with a main entrance at one end that incorporates two passenger lifts from platform level to ground level and ventilation fans, tunnel draught relief shafts and a fixed stair secondary exit at the other end. The perimeter retaining walls of the rectangular box are formed utilizing either secant piles or diaphragm walls. The retaining walls are extended below the base slab to sufficient depth to cut of the water flow into the station box during excavation.

Each station box is 64.4m-long but the width of the box is determined by the passenger requirements, which define the width of the platform. The station platforms are either 7 or 9m wide. Therefore the overall width of the deep stations is either 20.4 or 22.4m. The station grid is based on a 5.5m module. The platform levels are generally 20m below ground level, but for two stations this has been raised to 14m below ground level.

Within the box there is only one level of horizontal structure at intermediate level that provides permanent support to the deep retaining walls. There is a ground bearing reinforced concrete base slab that also provides long-term propping action for the retaining walls. The base slab supports the central island platform structure. The station box is envisaged as being built using top-down construction methods with the capping beam and roof slab being cast prior to excavation proceeding inside the box. Before excavation, a monitoring system must be implemented to measure and interpret wall deflections, axial loads in the slabs and ground settlement as well as the effects of ground movements on adjacent buildings and structures.

The main entrance, emergency exit stairs, ventilation ducts and grilles extend to the outside of the station box and require shallow excavations with retaining walls outside the station box. For four stations (Kobenhavn H, Kongens Nytorv, Osterport and Frederiksberg) there are transfer tunnels to existing stations. These excavations generally extend to a depth of 7 to 8m below ground level, corresponding to the concourse level of the stations. Depending on the local hydro-geological conditions and the vicinity of existing structures these excavations may be supported by pre-drilled sheet piles, king post piles or in the special cases by secant piles or slurry walls.

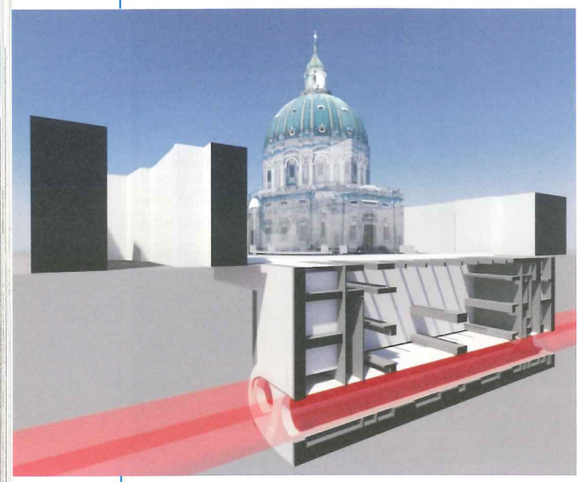


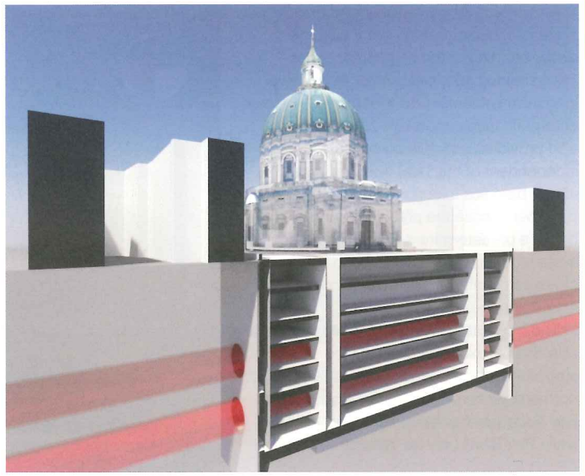
Above: **Figure 4, TBM groupings for 'Pair A' and 'Pair B' on the Cityringen project**

Design development - Marmorkirken Station

The layout of the Cityringen station at Marmorkirken is governed by the geometrical constraints imposed by the limited space between Frederiks Kirke and its neighbouring buildings and the importance of Frederiks Kirke as a historical landmark of Copenhagen.

The first design for Frederiks Kirke or as it is better known: Marmorkirken (the Marble Church) was from 1749. The Rococo-inspired design was not universally popular however, which led to a new design being drawn up in 1751 and in 1753. It was decided that the church would be constructed using Norwegian Gjellebaek marble. In November 1770, due to its unpopularity, a royal resolution drafted by Struense decreed that construction of the





Above left: Original station design near the location of the Marmorkirken or 'Marble Church'
Above right: Revised station design, modelled on a Roman metro station

Marble Church—as it had already become known—was to cease.

The unfinished church remained a ruin for more than 100 years until Carl Frederik Tietgen acquired the site in 1873. In 1876, Ferdinand Meldahl was given the job of finishing the church. The final design, which we see the result of today, was a rotunda in classic Baroque style. The oldest foundations and walls were used for Meldahl's church, and more than 100 years late, the church was ordained in 1894.

The original design of the Marmorkirken station consisted of a narrow station box, providing the space for a concourse area as well as escalators and a lift down to platform level, combined with a cavern widening at platform level to house a central platform of 7m. The technical rooms and the emergency stairs were arranged within two shafts at either end of the station box. The shapes of the shafts were adjusted to the footprint of Frederiks Kirke and neighbouring buildings.

The retaining walls of the narrow station box were propped at four levels by the roof structure, the concourse slab, upper technical level and lower technical level. The cavern at platform level had a permanent lining which is supported at the crown by the waling beams and struts at lower technical level.

The station was foreseen to be constructed using the top down method with the roof slab cast directly after the construction of diaphragm walls. As the excavation preceded downwards the internal slabs, beams and props were deemed necessary to provide the required stiffness to the diaphragm walls to minimise deformations and control potential surface settlements. Additional temporary props were forseen to minimise wall movement during excavation.

Ground freezing or permeation grouting was identified as a mitigation measures for control of ground water and settlements during construction the cavern. Once the effect of the freezing had been verified, excavation of the cavern was foreseen to proceed in steps until the whole station cavern was excavated, followed subsequently with the concrete of the cavern invert and crown.

The construction sequences, which were designed to minimise ground movements and water level fluctuations, required the setting up of an intensive monitoring program to ensure that the ground movements, surface settlements and water inflows were continuously monitored thus limiting the risk of unacceptable settlements to the surrounding area.

Revised station design

During the design development, the JV contractor of Salini, Tecnimont and Seli, Copenhagen Metro Team (CMT), proposed and alternative design of the station that was modelled on the recently constructed Station Piazza Bologna of Rome Line Three Metro, in Rome, Italy.

The revised design consisted of a narrow station box, providing the space for a concourse area as well as escalators with a stacked platform solution requiring the tunnels to run one above the other.

The concept of the stacked solution required a deepening of the station box but limited all works from concourse level downwards to be contained within the diaphragm wall retaining structure thus avoiding the necessity of cavern works or additional ground treatment such as freezing. As for the original design, the technical rooms and the emergency stairs are arranged within two shafts at either end of the station box.

As in the original construction sequence, the station is foreseen to be constructed using the top-down method with the roof slab cast directly after the construction of diaphragm walls, followed by the excavation within the box structure and the casting of each individual level of concrete slab, progressively working downwards towards the foundation slab.

The elimination of a cavern construction, the provision of a stacked tunnel alignment within the station box and adopting the top-down construction method enables optimisation of the construction sequences thus reducing the overall construction period for the completion of the station work.

The revised station design is more consistent with the other stations in the Cityringen project, albeit with a stacked tunnel as opposed to the required island platform, and provides more reliable groundwater control during station excavation and reduces the risk of delays.

The requirement for setting up an intensive monitoring program to ensure the ground movements, surface settlements and water inflows are continuously monitored remains unchanged.

Finnish access

Host city of WTC 2011 and capital of Finland, Helsinki is the world leader in planned underground space. Vaclav Pavlovsky and Ales Gothard explore Metrostav's involvement in tunnelling access shafts for a western metro expansion to the neighbouring city, Espoo

In September 2010 workers of Division Five of Czech contractor Metrostav started to drive three access tunnels for the Lansimetro ('West Metro') project linking the cities of Espoo and Helsinki, Finland. At the end of 2010 the company added to this by winning a contract for the construction of a 1.3km-long section of running tunnel for the metro and works have successfully commenced.

Metrostav operates in Finland as a member of a consortium, jointly with a local company Destia. Employees of Division Five are responsible for driving the tunnels, installing the excavation support including the final lining and grouting operations. The main task for Metrostav's partner is loading and removing the muck and, in the case of the access tunnels, preparing cut and cover portal sections and sinking three ventilation shafts on the track section.

The Lansimetro project provides a new transportation link between Helsinki and Espoo, with a capacity of 100,000 passengers a day. It directly links to the only operating metro line. Increasing demands for transport required the neighbouring cities to be interconnected with the new 14km link. The existing backbone metro line with the annual carrying capacity of 50 million passengers is 21km-long. It was constructed between 1969 and 1982 and was extended eastwards in 1998. After completion of the new section, the whole metro line will be fully-automated and driverless.

The new line runs underground from Ruoholahti in Helsinki, to Matinkyla station in Espoo. It consists of a pair of single-track running tunnels, connecting seven new stations with 15 ventilation shafts. The whole route is divided into 10 sections for tunnelling purposes into, requiring nine access tunnels to be driven in aggregate length of 2.5km. This will create an anticipated total volume of muck of 3Mm^3.

The estimated project cost is EUR 714M (USD 929.2M), 30 per cent of which is provided by the state. The remaining part is divided proportionately to the respective lengths of the route between the city of Helsinki (28 per cent) and Espoo (72 per cent).

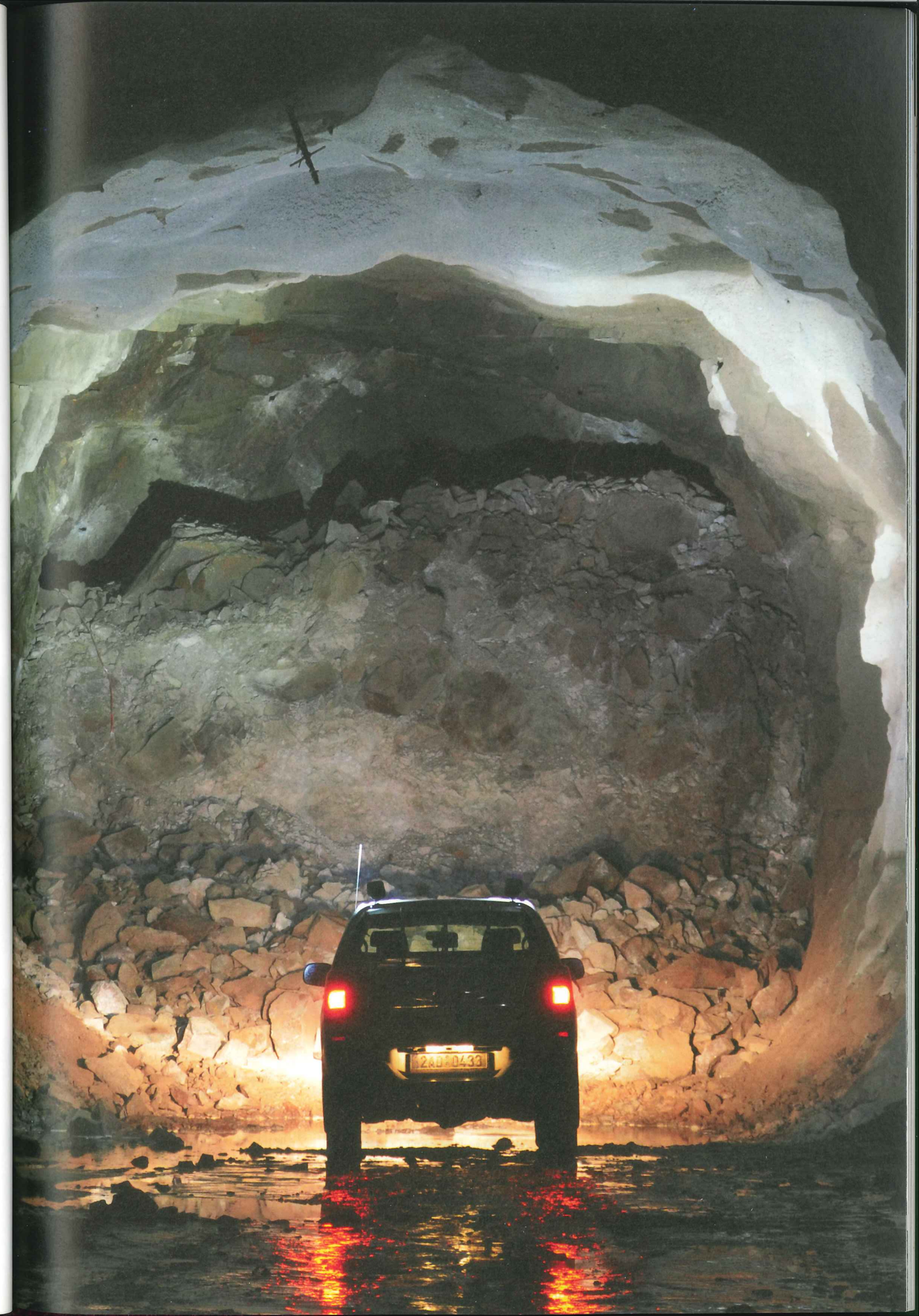
Project go ahead was given in 2006, and the deadline for bringing it into service is the autumn of 2014. Nearly 400 designers worked on the design during the planning and design phases. This, the largest infrastructure project in Finland, is managed by Lansimetro.

Access tunnels construction

The three downhill gradient access tunnels are Lauttasaari (405m), Myllykallio (283m) and Koivusaari (567m). They provide points of access to the running tunnels of the metro. They are located in the centre of a residential development on Lauttasaari Island. The cross-sectional area of the tunnels varies from 31 to 58m^2, the rock cover is 5 to 40m high. From the geological point of view, the excavation passes through hard rock, mostly granite, and under the water table. The quality of the rock mass is generally very good, and favourable for tunnelling. However, it is variable, ranging from sound compact formations to significantly fissured local failures draining groundwater and sometimes containing sedimentary intercalations. Quality of rock mass is assessed using the Finnish engineering geological classification system (RG) (Korhonen, 1974). It provides an objective description of properties of rock mass, consisting of:

- The degree of weathering, sizes of

Left: **Figure 1, the project's location between the two cities**
Right: **A tunnel for the Lansimetro**



Left: Figure 2, the project alignment

minerals and their representations
- Mineralogical hardnesses
- Degree of fracturing
- Filling of joints

The 1.3km long track section (LU6E) – Karhusaari links with the metro on the border of Helsinki and then proceeds westwards to Espoo. Part of the tunnelling contract is for a pair of single-track running tunnels with a distance between centres of about 25m. The common tunnel profile area is 36.2m². The tunnel tubes are interconnected by cross passages roughly every 200m. Two single-vault technical services chambers are designed for this section. The excavated cross-sectional area of each chamber is 318m²; the length is 35m. In addition, three rectangular vertical ventilation shafts of 9.4 x 6.5m are part of the job. The alignment of this section, running from the east, runs partially under the sea; then it crosses an express highway and, at its end, passes under foundations of a Nokia administrative complex. The overburden height varies from 35m to a mere 15m under the sea bottom. The excavation of the tunnel tubes proceeds slightly uphill to both sides from the point of attack provided by the 280m-long Karhusaari access tunnel.

The mined sections of the Lansimetro project are a typical example of the drill and blast tunnelling method, which is exceptionally suitable for Scandinavian geological conditions. It is a cyclic method of disintegrating rock by blasting, proceeding full-face with the excavation rounds up to 6m-long. The zone ahead of the face is stabilised with cement grout (pre-grouting) up to the distance of several round lengths. The single-shell final lining of the tunnel consists of rock bolts and shotcrete.

Blasting operations are especially thoroughly monitored, first of all in the case of the excavation of the access tunnels, which run under dense development, with the overburden height gradually growing. A condition survey of buildings above the route of the mined tunnels was conducted before starting the excavation.

The working time available for blasting operations is from 7am to 10pm; it is restricted only to working days. The area affected by the construction works was determined before the commencement of blasting operations by a risk analysis.

The permissible loading induced by seismic effects of blasting (vibration in mm/s) is specified for each structure. These values are monitored online, and the results are automatically placed online and sent by text messages to the owner and tunnelling contractor. This is why the production drilling accuracy, proper structure of charges and, most of all, priming the delays are very important. Even though the geological conditions allow the application of the maximum round lengths in terms of the drilling technology, each excavation face has to be approached individually.

If necessary, round lengths have to be reduced even to 2m, taking into consideration the charge weight limits. Emulgit-type explosives are used for the rock disintegration, both in the form supplied in cartridges and in the form of pumped emulsion. Explosives are initiated by non electric detonators. Cuts are straight with four relief wells 102mm in diameter; common diameters of production boreholes range from 45 to 54mm. The tolerance specified in the design for unavoidable overbreak is +400mm for side walls and the crown and +600mm for the tunnel bottom. Muck is removed to a central stockpile, where each truck passes a quality check, ensuring that only disintegrated rock containing no contaminants (sediments or shotcrete rebound) is deposited into the sea. When the muck has been removed, it's necessary to clear the excavated surface by a scaler fitted to the excavator boom. The use of hydraulic hammers is not permitted.

Before the excavation starts, four 25m-long probe holes located on opposite sides of the face are drilled. During the course of drilling, the rate of the penetration of the drilling tool, the drilling fluid and the position and amount of water encountered (if any) are followed and recorded. The absorption capacity test is conducted on each borehole. During the test the borehole is sealed by a packer and pressurised with water at 0.5MPa. The drop in water pressure in the borehole is monitored after five minutes and Lugeon's criterion is determined. If the criterion value is equal to 0.8 or higher, drilling for a protective grouting umbrella consisting of 20 boreholes 25m-long is carried out and grouting operations starts. The entire process is regularly repeated every 20m of the excavation, which means that the overlap of individual umbrellas is 5m.

Rapid-hardening cement (d95 < 20µm) is used for the grout mixture with the w/c ratios ranging from 1 to 0.6. If the consumption of grout is high, it is possible to use rapid cement (CEM II 42.5 R). The cements used for the grout must meet requirements of cement standards SFS EN 197-1+A1. After the basic grouting is completed, it is possible to start to drill the production holes only if the grout stands seismic effects of blasting and is not washed out together with the drilling water. The minimum times for starting the drilling operation and for the execution of blasting, measured from the end of grouting, are six hours and 10 hours respectively. Reducing the duration of the technical break is conditioned by proving sufficient strength of the grout. The criterion for the success is the adherence to the following tunnel tightness classes prescribed by the design:

- Class AA water seepage rate < 2 l/min/100m for running tunnels
- Class A water seepage rate < 5 l/min/100m
- Class B water seepage rate < 10 l/min/100m

If more water seeps to the tunnel in the particular section then the design prescribes that the area must be post-grouted. The grout is pumped into boreholes using an Atlas Copco Unigrout EH 45-200-2 x 110 MWB set.

Rock bolt strategy

Rock bolts used as the excavation support are divided into the following categories:

- Rock bolts installed before the commencement of excavation (first of all before the excavation of portal sections)
- Temporary rock bolts, interrupting the excavation cycle
- Permanent rock bolts, forming a part of the final lining
- Supplementary rock bolting support.

The rock bolts interrupting the excavation are installed in locations specified by the design or when there is a threat of loosening rock blocks jeopardizing the safety at work. Temporary mechanically expanded rock bolts of 3 to 5m-long are used first of all, allowing post-grouting before the shotcrete is applied. If they meet corrosion protection requirements, they can be recognised as parts of the final lining.

The permanent rock bolts are from deformed reinforcing bars 25mm in diameter and 3 to 5m-long, which are installed systematically in a 2x2m grid. The rock bolts are not equipped with faceplates and are not activated in any other way. The installation of permanent rock bolts must follow after the excavation at a minimum distance of 30m from the excavation face so that the effects of blasting operations on the grout are eliminated.

Supplementary rock bolting support comprises, first of all, Titan 40/16 self-drilling anchors, forming up to 12m-long protective umbrellas in the locations of deteriorated geology. The installation of 45,000 self-drilling anchors is expected for the LU6E track section (1.3 km). In the area of driving under the sea surface, the existing reinforcement is enhanced with an additional 44 radial rock bolts per linear meter of the tunnel.

The rock bolts are made of A 500HW steel. All permanent support elements must have corrosion resistant finish consisting of a 105µm-thick hot-dip galvanized coat and a 300µm thick epoxy coat. The rock bolts provided with the corrosion protection are supplied by Minova Bohemia. The grout is a mixture of common Portland cement and sand (maximum grain-size of 2mm), which are mechanically mixed in the ratio of 1:1, with the maximum w/c of 0.4. The grout strength grade is C30/37. Environmental exposure classes are XA2 and XS2. The design life of the rock bolt support is 100 years.

All drilling is carried out using three Tamrock Axera T11- 315 TCAD semi-automatic triple-boom drill rigs. The rock mass contains a high proportion of hard materials including feldspar and quartzite, which are highly abrasive. The drilling bits last only for several tens of meters, but they can be resharpened and reused once or twice. Similarly to the rock bolts, structural concretes are also divided into basic categories:

- Shotcrete applied immediately during the course of the works, which means interrupting the excavation,
- Application of final lining shotcrete.

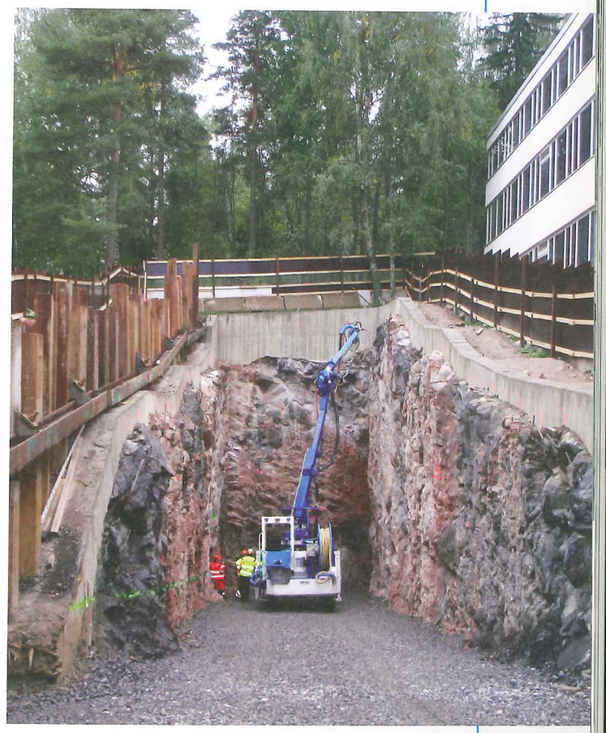
The immediate application of fibre reinforced (60kgm³ of steel fibres) shotcrete is performed in worsened geological conditions with the aim of increasing the level of safety at work.

The final tunnel lining consists of two layers of concrete. The initial layer is structural, 30 to 100mm thick, again reinforced with fibres. In the case of running tunnels, polypropylene fibres (about 7kg/m³) are used instead of steel fibres. The second layer, 30mm thick, is from unreinforced concrete and is considered to have a protective purpose. Identically with the case of final rock bolts, even the shotcrete lining must follow after the excavation at the distance of at least 30m from the face. Cross drains are installed in the cases of contingent local dripping.

Material requirements for the quality of shotcrete are based on the SFS-EN 14487-1 and SFS-EN 14487-2 standards. The maximum size of aggregates in the concrete is 8mm. Portland cements are used as the binder. When the wet process is applied, the maximum w/c ratio is 0.5. The amount of water in the concrete mix must not exceed 200kg/m³ (slump of 100 to 150mm). The density of fresh concrete must be higher than 2,200kg/m³. Dosing of setting accelerator must not exceed five per cent of the weight of cement. This relatively strict requirement is met by Sika Sigunit L53 AF-S accelerators. Curing agents are not permitted. Water mist must be sprayed on the surface for 14 days after the application as the minimum, or until 80 per cent of the nominal strength is reached. The quality of the resultant concrete reaches the grade C30/37, XC3, XF1. The minimum energy absorption capacity at the plate test (at deflection of 25mm) must be 1000J. The steel fibres used must be longer than 25mm. The yield strength of the fibres must reach 800MPa as a minimum and their ends must be widened or provided with hooks. Fresh concrete mix is transported to site in mix trucks and is applied by a Meyco Potenza manipulator.

The teams onsite follow a six-weeks on duty, alternating with three-weeks off working pattern. The miners work a six-day, two, 12-hour shift operation with four men in a shift. The excavation proceeds during working days at the average advance rate of 3.5m per heading per day, while the final lining is erected on Saturdays. The total number of employees of Division Five (including miners taking time off work) is 31.

By the end of 2011, the Myllykallio and Koivusaari tunnels were all complete and had been handed over. The final access tunnel, Lauttasaari, was completed in autumn. Driving of the running tunnels began in June and the completion, including all associated structures, is planned for the first quarter of 2013.



Right: Construction for the Cityringen project

Abu Dhabi's first Step

T&TI investigates the first major mechanised project for the Emirate in this special insight

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 with a length of 40 kilometers, as well as inflow and pump stations.

Herrenknecht is delivering five tunnel boring machines (EPB Shields ∅ 6,130 and 6,950mm) for the project. They are designed to withstand high groundwater pressures of up to 8bar, and they are the first tunnel boring machines of this size in Abu Dhabi. In April 2011, the tunnel boring experts from Impregilo S.p.A. drove the first tunnelling meters, and have rapidly and safely advanced since then. The concrete components for the tunnel lining are delivered by a lining segment production plant installed on 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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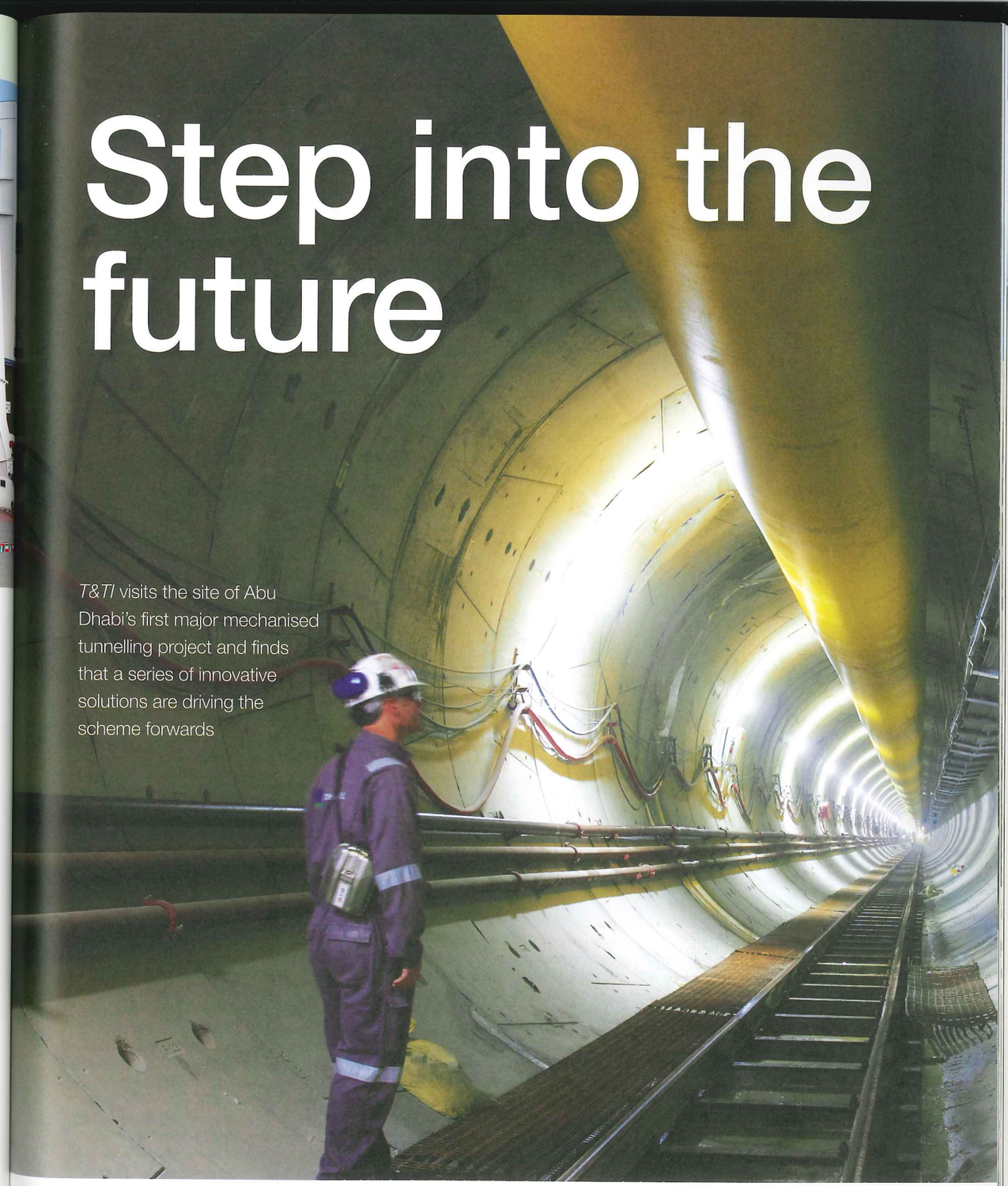
Tunnelling Systems

Step into the future

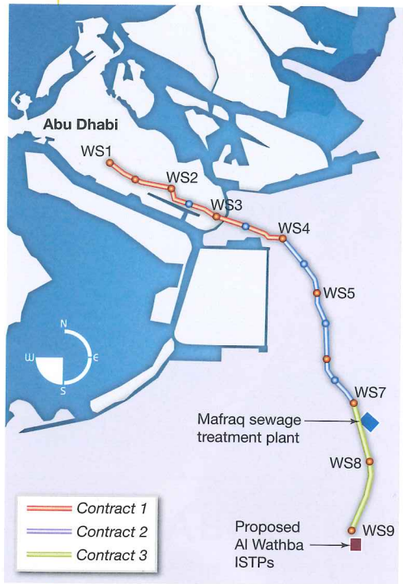
T&TI visits the site of Abu Dhabi's first major mechanised tunnelling project and finds that a series of innovative solutions are driving the scheme forwards

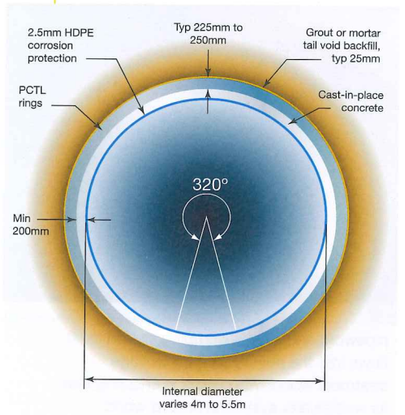


November is one of the busiest months of the year for the Middle Eastern Emirate of Abu Dhabi. As a host of the Formula One Grand Prix event the city welcomes 50,000 spectators, thousands more team personnel and of course the world's media. As this activity buzzes on the surface and thrusts Abu Dhabi under the international spotlight, most people do not realise that at the same time work ongoing underground is set to ensure that Abu Dhabi can retain its international high profile long into the future.

By constructing a new 41km-long, deep sewer tunnel, with a network of connecting pipework and a huge pumping station to lift flows into the new Al Wathba sewage treatment works, Abu Dhabi is ensuring that its wastewater system is fit for a world leading city of tomorrow.

Achieving this is of course a huge challenge for all involved including the sewage service provider Abu Dhabi





Left, top: **Figure 1, alignments of contracts one, two and three of Step**
Left, middle: **Figure 2, map showing links to pumping stations from deep sewer**
Left, bottom: **Figure 3, tunnel section**

Sewerage Services Company (ADSSC), programme manager for the scheme CH2M Hill and main contractors Italy's Impregilo and South Korea's Samsung C&T Corporation.

"The biggest challenge is that this is a massive programme. Massive in terms of monetary value, massive in the sense that it stretches over a long timescale and massive in the sense that the public sector has never done such a programme in this region," says the manager of ADSSC's programme management department Shahzad Orakzai.

However, under ADSSC's watchful eye these organisations and their designers and suppliers are bringing new technologies, working methods and contract forms to the Gulf. And despite the AED 6bn (USD1.6bn) project, branded the Strategic Tunnel Enhancement Project (Step) still being in the construction phase the perception of success has already led to other local and national clients replicating the model (see feature, page 46).

Contract packages

Upon introducing the project to the market in 2008 the management team carved the tunnel into three main contract packages and eight bores of around 5km to attract world leading contractors. This attracted over 45 expressions of interest for the scheme, which also included the link sewer contracts and the pumping station. CH2M Hill's STEP programme manager, Bob Marshall says, "We were very pleased with the response which was better than we expected in some respects. At the time when we were doing this there was a lot of work world wide, but the size of the project was large enough to attract international contractors."

The team narrowed these firms down to a list of 15 and then assigned them to bid for certain contracts depending on how they scored in the prequalification evaluation. In September 2009, Italy's Impregilo became the first contract winner, securing the AED 891M (USD 243M) contract for package T02. Involving three major work shafts, three additional access shafts and a total of 15.5km of tunnelling this section forms the centrepiece of the sewer and ranges in depth from 43m at the north end at work shaft five (WS5) to 61.9m at the southernmost point work shaft seven (WS7).

Two years later the contractor has excavated 6,187m of the tunnel consisting of 4,419 of the 1.4m wide rings. These have been excavated along three separate bores and by the end of November 2011 contract T02 was 41 per cent complete. "On 23 November we had our best overall day with a total of 67 rings installed. This was also the best day per TBM with 30 rings for TBM Two," says main contractor Impregilo project manager Richard Graham.

In order to see one of the 6.3m diameter Herrenknecht EBPMs in action T&TI visited work shaft six and took a ride down the tunnel face where the machine's 16 pairs of hydraulic cylinders were propelling the 500t excavator forwards and 32 of the seven inch cutters were working their way through the mixed face conditions of gypsum and mudstone. Site and TBM manager for Impregilo, Emidio Tamburri, tells *T&TI* that creating the shafts themselves was the first major issue. "For me the biggest challenge has been the shaft excavation. We had to excavate and at the same time remove the material with three or four people down the shaft, so we had to be really coordinated and responsible and use experienced people," he explains.

Ground conditions were stiffer than expected, allowing SCL use on the shafts

Fortunately the ground conditions turned out to be stiffer than expected and allowed the contractor to switch from a diaphragm wall construction used for the majority of the 16.2m wide shaft to sprayed concrete for the lower section, accelerating progress and reducing cost on the design and build job.

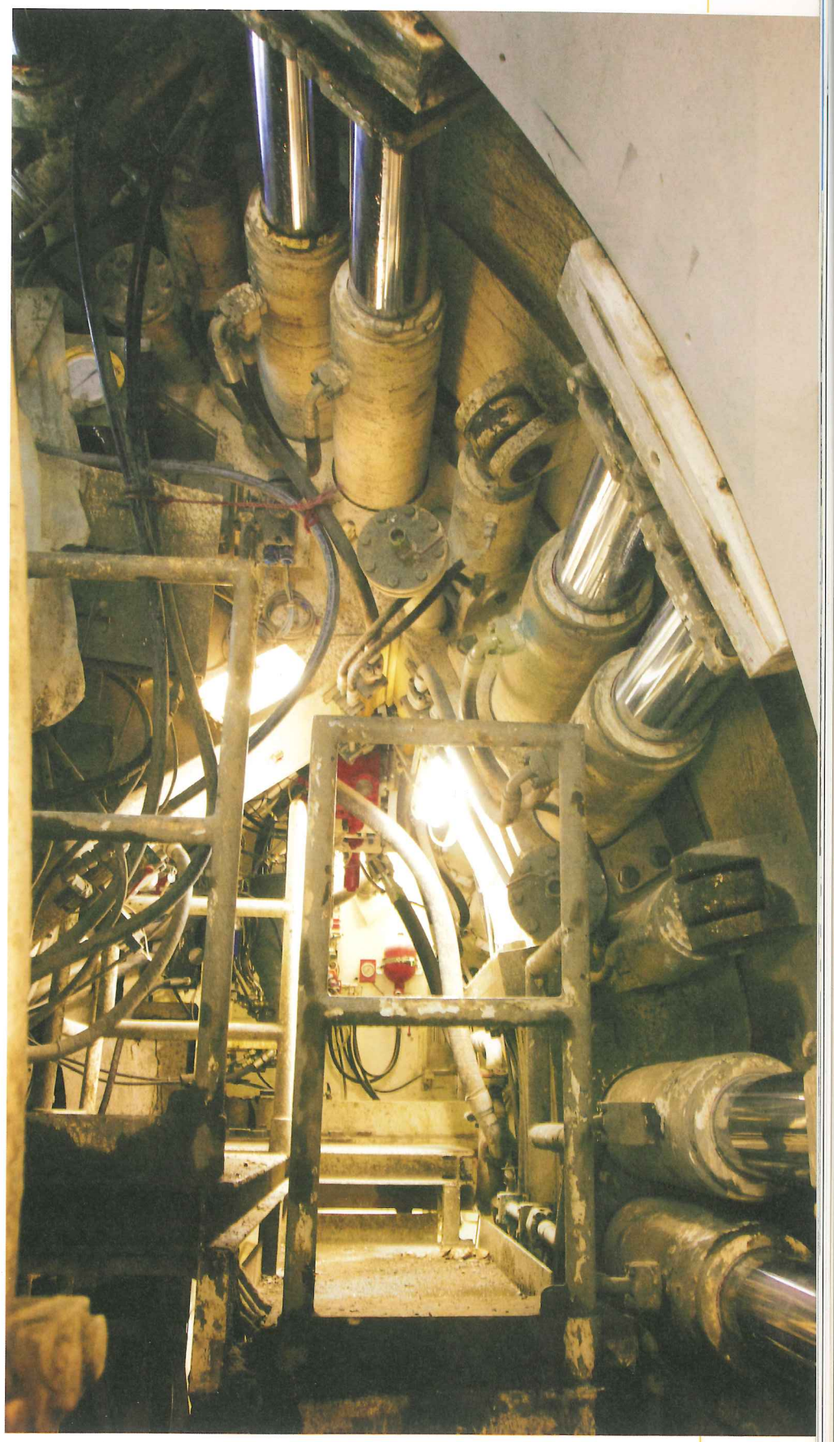
The next major challenge was installation of the first TBM in October 2010. This would be required to bore uphill from WS6 to WS5, a total length of 5,303m. A particular challenge for the contractor was the tight tolerance of the launch tunnel. "The second major challenge was the launching of the TBM," says Tamburri. "We had a gap either side of just 20mm."

Launching the machine was carried out in two stages. The actual TBM was assembled on the surface and lowered down the shaft in one go, using a 600t crane. The tailskin and first four gantries were then lowered and connected as the TBM was progressively pushed towards the launch chamber front. The service supplies were connected with temporary umbilical cables and pipes. "In this configuration we partially commissioned the machine and then excavated the first 46 rings, thereby creating space within which to complete the remaining four gantries," explains Richard Graham. During this phase mucking was temporarily undertaken with muck skips.

Following the launch the work could get started in earnest and the planned excavation rate was 22m per day, equivalent to around 16 rings. Although Impregilo is now exceeding this, progress was slower in the early days of the bore, when issues with the grouting led to some movement of the rings and localised cracking. "This was due to a combination

Table 1: Contract T02 progress

TBM	Work shaft	Nov '11 progress	Total bore length	% of total
EPBM 1	WS5	417m	2464m	50
EPBM 2	WS6	678m	1981m	38
EPBM 3	WS7	650m	1560m	32



Left: Contractors place the rails from back to front allowing the TBM to continue moving forward
Right: The machine is propelled by 16 pairs of hydraulic cylinders

of factors concerning the grouting system," says Impregilo's Graham. "It was a case of ensuring that the correct procedures were being followed and defining the correct parameters for pressure and volume that were correct according to the advance rates we are trying to achieve. We consider it part of the commissioning process – you never start at high speed."

Fortunately for the project the cracking in the fibre reinforced segments had no structural implications. "There are no issues in terms of structural stability and durability associated with the cracking of the segments because these are fibre reinforced," says Marshall.

The use of fibre reinforcement on this project was particularly important because the ground conditions in Abu Dhabi are extremely aggressive, with salinity at four times the level of sea water. "Designing the concrete mix of the segments took over a year. Getting the concrete right was extremely challenging," says Graham (see feature, page 50 for more on segment design).

Having resolved the earlier issues the team is now making good progress. All three of Impregilo's bores are driving hard with EPBM number one having made it to half way on its 5.3km bore (see table one, page 39).

Working hours on contract T02 are practically constant however the team must take a two-hour break every 24 hours. "Working hours are 7am to 6pm then with a two hour stop, which is a legal requirement. The next shift then continues working from 8pm to 7am. Every three weeks we change over shifts," says Tamburri. Inspections of the cutter heads have been carried out every 250m coinciding with the need to extend the 11,000V HV cable, but as *T&TI* visited there had not yet been the need to make any changes. This is partly due to the favourable ground conditions. Across all of the contracts, T01, T02 and T03 the contractors confirm that so far the ground has been better than expected. "It is ideal tunnelling material," says CH2M Hill resident engineer for T02 Bill Brundan. The mudstone and gypsum have been drier than anticipated and so far there has been no sign of any voids, which can form between the strata layers thanks to gypsum's tendency to dissolve in the presence of water.

Above: **The third EPBM is lowered into its launch shaft on contract T02**

However a side effect of the dry ground has been the need to adapt the soil conditioning process. "Due to the face conditions being drier than expected a wetter conditioning mix is used. The result is that the spoil removed from the face is wetter than originally expected and is therefore not suitable for the existing landfill location," explains Brundan.

Finding a new landfill site suddenly became a critical issue that required the combined efforts of the entire project team to solve. "Because all of the agencies required to give approval are government bodies, ADSSC has intervened and been dealing with the Municipality," explains Marshall. "They got an allocation of land out in the desert beyond Mafraq designated as a spoil disposal site for Impregilo and there will be an adjacent site for Samsung and the other contractors. There was a brief panic when we realised that there was refusal to accept the spoil but after negotiations we found an area to spread it on so that it can dry out and then it is OK," says Marshall.

Breakthrough for all three of the EPBMs currently working on T02 will be staggered throughout mid 2012 and although this represents a huge achievement for everyone involved, there are still the bores on contracts T01 and T03 to get started. Successful breakthrough also represents the commencement of another critical path activity – construction of the internal 250mm-thick concrete secondary corrosion lining. Impregilo are planning to use a tried and tested in-situ pour, whereas on contract T01 Samsung C&T say they are considering a pipe jacking solution.

One area where all project parties have been challenged has been on getting the necessary stakeholder approvals for construction of the work shafts. "Permitting is one of the most difficult challenges around," says CH2M Hill's Brundan. "The contractor has to get approval from 20 to 25 different authorities for each stage of the work. In this area we have an oil pipeline, water mains, sewers, fibre optic cables. You have a myriad of different utilities. Each one owns a different section of land which is protected as a utility corridor."

As a result of the congestion of services most of the shafts had to be moved and a lot of time has been spent liaising with local utility providers. "Right at the beginning in the contract it said we had to contact 76 different entities," says Graham. "We then took their comments to the Municipality and asked 'can we start the work?' They asked us if we had manually dug a trench across the site to verify the services information."

So before any permissions could be sought the contractors had to hand dig a trench to verify the location of services and then produce new 'as built' drawings showing their location.

Mechanised tunnelling was also so new to the region that stakeholders did not realise at first that the new tunnel would not create problems on the surface. "Getting through to people that there would be no surface disturbance was a big challenge," says Graham.

Overcoming challenges has been a key feature of the project to date and no doubt more hurdles will be faced and overcome before the STEP system is fully operational towards the end of 2014. "You are always going to get technical challenges in a contract of any size and a tunnel in particular being done for the first time in this part of the globe, to get that right first time would be a miracle," says ADSSC managing director Alan Thomson. "With all the best will in the world you are still going to come across the unexpected."

Dealing with the unexpected is much easier when all parties pull together, as has clearly been demonstrated on the STEP project. By uniting in the face of challenges the grouping is clearly more than just a sum of its parts.

By continuing to work this way Abu Dhabi is sure to get the world class wastewater infrastructure that it has been waiting for.

T03: The end of the line

The deepest section of the sewer was awarded to Impregilo in November 2010. The contract involves construction of work shafts eight and nine and a 9.7m bore between works shafts seven and nine. The deepest shaft, number nine goes down to 79.7m. This drive is slightly larger than T02 with a 6.98m external diameter providing space for a finished internal tube of 5.5m diameter. From work shaft eight CH2M Hill resident engineer Mark Marshall explains what work is underway. "This shaft is now complete and we are constructing the launch and reception adits. WS9 is being excavated at the moment. We have a drive from here to WS07 of 5.4km. WS9 to WS8 is 4.3km."

Each of the workshafts is approximately 17m in diameter, much larger than the two 7m diameter access shafts that are also required in this section. "As on all shafts the diaphragm walling goes to 45m and beneath that it is sprayed concrete lining," says Marshall. "Originally it was full depth but the contractors designer looked at it carefully based on the experience gained in T02 and did some value engineering and calculated that they could use diaphragm walling and SCL system.

The diaphragm walls themselves are 1m thick, and the sprayed concrete lining varies between 700mm and 400mm as required. The first EPBM is set to begin arriving in December with a surface assembly before lifting to the base of WS 8 – the same method as T02. Launch adits are being excavated using NATM. "It is very good ground so the contractor is doing 2m advances, full face and spraying concrete as necessary," says Marshall.

"On this section of works we have not faced too many challenges. The heat and the humidity in the summer could be a challenge, but it is managed fairly well by all involved. During the height of summer we can get temperatures in the very high 40s and it can be very brutal."

The team is working towards a launch date of March 2012 for the first TBM followed by mid May for the second. Boring is scheduled for a January 2013 breakthrough in both sections.

T01: Taking it from the top

Contract T01 was awarded to Samsung C&T Corporation in February 2011. It includes construction of five work shafts, three access shafts and three major tunnel bores making up a total section length of 16.1km. Testing of the first 5.3m Kawasaki EPBM has just been completed in Japan, meaning that the contractor is on schedule to see the machine arrive in January 2011, with the second machine arriving in February and the third in March.

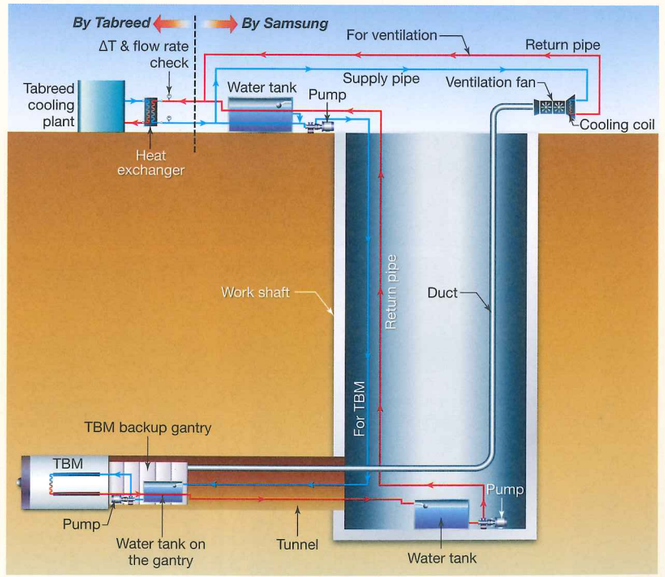
In the meantime the site team are finalising the ground investigation studies and preparing the work shafts in advance of the TBM arrival. Works shafts three and 3.1 have been completed and permissions for work shafts one, two and four were granted in December. "We are doing a lot of ground investigation at the moment," says construction manager for Samsung C&T Lee Pearson. "By the creek we found some very soft clay, which would have had an impact on the tunnel design, so we did some further investigation."

Fortunately this further investigation showed that the clay was just an isolated pocket. "We also spoke to the people that built the Mussafah Bridge who also told us that they had no problems."

As on the other contracts, Pearson says that the contractor is expecting to be in good ground. But they are taking precautions to ensure that they are prepared for potential voids. "We have a ground prediction system that looks about 12m ahead and will show any anomaly. If you come across a big void we can put probes out and do forward grouting," Pearson says.

An innovation that Samsung plan to bring in to their project is to take advantage of the local district cooling company Tabreed National Central Cooling (see diagram). "They will supply us with water at 7.2 degrees which will be good in the summer when it is 50 degrees outside," says Pearson. Harnessing the power of the local cooling provider means that Samsung could make major costs savings. "It costs USD 5M to buy cooling plant plus there is the electricity usage."

Another area where the company is looking to save time and cost is on placement of the secondary lining system for the tunnel. "Rather than taking formwork in we are thinking of jacking the pipe through and grouting it in," says Pearson. "We would push the pipe through with the HDPE inside already. It would give us a massive advantage," he says confirming that any savings are split between the contractor and the client.



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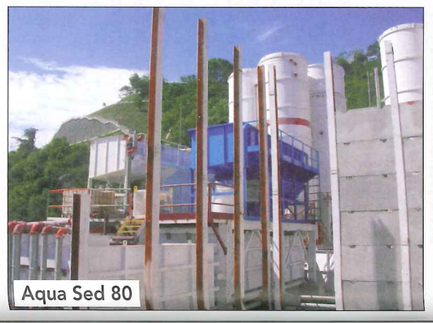
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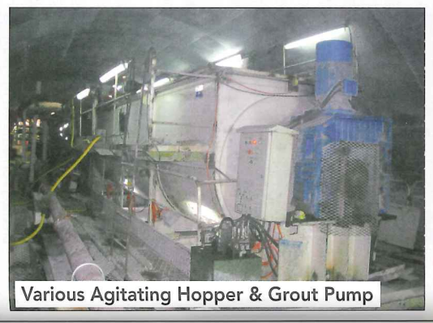
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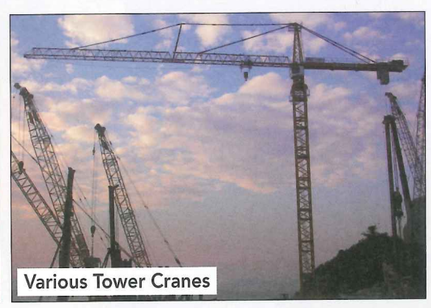
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Take a new approach

Abu Dhabi's public sector has pioneered a range of contract approaches to ensure successful delivery of its new super sewer, Bernadette Ballantyne reports from site

Abu Dhabi Sewerage Services Company (ADSSC) urgently needs to increase the capacity of its wastewater network and is currently implementing a masterplan worth AED 20bn (USD 5.4bn). "Our existing system is already working over capacity," says ADSSC managing director Alan Thomson. "The gravity sewers are in a surcharged condition at peak flow."

Delivering the masterplan, which includes the AED 6bn (USD 1.6bn) Strategic Tunnel Enhancement Project (Step) is a huge requirement for the utility provider, but ADSSC has come a long way since it was launched as a fully independent entity in 2009.

"Prior to 2005 we were a small group in Abu Dhabi Municipality running a fantastic show given the resources we had," explains the manager of ADSSC's programme management department Shahzad Orakzai. "The government anticipated a big boom, they knew demand would increase, hence we as an entity were formed as ADSSC, which was part of Adwea for quite a length of time."

Vision to reality

Adwea is Abu Dhabi Water & Electricity Authority, but in 2009 ADSSC was given full independence to continue delivering its masterplan. "Our masterplan has been the key driver behind the capital investment plan. From this we have a hydraulic model, and a basket of investments. Once that was done we knew from the hydraulic model that if we didn't improve the infrastructure based on these schemes by 2015 we would have flooding almost everywhere," says Orakzai.

The findings of the hydraulic model were critical to the outcomes of the masterplan so validation of this was a major part of the process. Finally in April 2007 the model was frozen and by December 2007 the masterplan, which was developed with consultants GTZ and Dornier, was completed. It enabled ADSSC to develop short-, medium- and long-term infrastructure projects that would ensure that Abu Dhabi could continue to service its fast growing population. Central to this was the sewer proposal. "The whole Step concept has been validated seven times from different perspectives by different entities," says Orakzai.

Meanwhile reports of localised flooding incidents were placing additional pressure on ADSSC to improve the system.

Despite the clear need for major new capacity in the system, ADSSC had a major challenge on its hands convincing all stakeholders that a tunnel was the right solution for Abu Dhabi. "One has to appreciate the local perception of tunnelling. The perception has been a negative one and I must say that this is not based on practical evidence but on the presumed geology of Abu Dhabi Emirate," explains Orakzai. "Generally the decision makers perceived that there were huge cavities everywhere.

"When we first started talking about a solution to Abu Dhabi's sewerage needs in 2006 the first reaction of our senior members was: 'absolutely not, the roads will cave in and houses will collapse. Let's do something smaller'. It was very difficult to successfully cross that initial barrier."

Digging deep

At the same time mechanised tunnelling had not been done in Abu Dhabi before so people understandably expected that disruptive cut and cover methods would have to be used. However over time ADSSC convinced the authorities that not only could the deep tunnel be safely constructed without disturbing homes and businesses, it was the best option for providing the much needed new capacity and ensuring that there would be no issues with odour developing.

Although in the past voids and cavities have been a feature of the ground conditions thanks to the soluble gypsum layers in the strata, incidents so far reported have been at a higher level than the Step scheme, which begins at 24.3m below ground level and ends at 79.7m below ground level.

Additionally both ADSSC and the contractors have carried out extensive ground investigation to provide more certainty over the tunnelling conditions. Measures available on the EPBMs themselves to mitigate voids including forward probing and grout injection have also helped to reassure stakeholders.

Gaining support

With the tunnel gaining support it was time for the client to consider what delivery mechanism would be most appropriate for the huge project. "ADSSC decided that with Step they had to do something different," explains Step programme manager for CH2M Hill Bob Marshall. "Shahzad was looking at other examples where similar schemes had been delivered using programme management including DTSS in Singapore (where CH2M Hill was programme manager) among others. He decided that that was a better model for delivery."

Above: **Shahzad Orakzai, manager of the Abu Dhabi Sewerage Services Company programme management department**

Orakzai says that key to the decision to use a programme management approach was the desire to create a collaborative working environment. "Generally speaking on the relationship side, within the public sector the approach to private sector is usually not supportive and is more confrontational. We challenged that philosophy and made this more like a partnership. We have an open book contract with CH2M Hill and we brought them into our offices."

Beyond the team environment

Below: **Bob Marshall, CH2M Hill's STEP programme manager**

Above: Alan Thomson is managing director of the Abu Dhabi Sewerage Services Company

programme management differs from the traditional project management process by allowing the client and its programme manager to look at the whole system and break it up in the most efficient way. "It allows you to figure out the best way to deliver. Is it design and bid approach, is it design, bid, build. What conditions of contract are appropriate across the whole system? You look at design as an entity, then building appropriate management of interfaces between the contract into the contract documents so that you have consistency across the project from design documents to constructability, contract documents and operations and maintenance," explains Marshall.

The team ended up with a series of six major contracts, to be carried out under design and build contract conditions using a modified version of FIDIC. "When the first tender documents went out at the end of 2008 design and build had never been tried by the government until this project," says Orakzai who says that without the openness and support of senior ADSSC and government members these initiatives could not have been introduced.

"Design and build has worked very well," says Thomson. "It allows freedom for the contractors and consultants to use their experience and also to bring their expertise to the table. Partly this is down to personalities – but having CH2M Hill bridge the gap means anything that is a problem in one area can be avoided in the future. Contractors here are quite comfortable with that approach."

Risk placement

Furthermore to make the contract packages attractive to the world's best contractors ADSSC had to adapt the contract conditions to incorporate the risk of unforeseen ground conditions. "At Step we prepared a third version of FIDIC. The key clause, which was the most difficult to push through for approval was unforeseen physical conditions," says Orakzai. "That was primarily driven by the usually adopted tunnelling industry practices from an insurance viewpoint."

Marshall adds, "Taking this risk as the client was crucial. Putting the ground condition risk with contractors would have led to firms dropping out because of unacceptable risk, or putting silly prices in."

Another contracting initiative that has saved the client money was the decision to include a cost adjustment clause.

Step construction manager from CH2M Hill Patrick Doig says, "Concrete and steel were at a peak (in 2008) so we didn't know where this would meaning that contractors were at an inflated risk.

"As it turns out it has benefitted the client as it was a negative change. Concrete dropped back in excess of 50 per cent. Steel peaked and has now levelled off again. That was a good step for the client to adopt."

Given the timing of the Step, which was launched in 2008, there have obviously been some impacts from the global credit. International issues had a local impact with Abu Dhabi lending over AED 10bn (USD 2.7bn) to neighbouring Dubai to ease its credit woes. Following on from this Abu Dhabi carefully re-examined all of its projects, growth forecasts and expenditures, and this has caused a delay on contract award.

Although all three tunnel packages have now been let, these were spread over a longer timescale than originally envisaged. "Originally we were looking to complete the project by the end of 2012. Now we hope to do this by the end of 2014 but that may be optimistic and it is being reviewed," Thomson says.

Compartmentalise

Fortunately the structure of the programme means that each section could be constructed independently of the others. "We spent a lot of time looking at ways of delivering the system such as breaking down packages into smaller contracts to get approval faster," says Marshall. "Initally we kept a full team on for a period but it got to a point where ADSSC said you need to downsize and focus on running T02 until the other contracts are awarded.

"One of the things that has helped is that we are on a fully reimbursable form of contract as the scope has evolved and changed, so this was really the only way to manage the programme."

Knowledge transfer

As well as being the programme manager, CH2M Hill also has a responsibility to its client under the contract to provide professional training in both an active and passive way. So work shadowing, formal training courses and mentoring are all important components of the project.

"We are looking at trying to integrate more Emiratis into the process so that there is knowledge transfer," says Thomson. "It is a massive opportunity to see how these huge contracts are operated and put together. It is fantastic opportunity."

Measures such as this are ensuring that ADSSC continues to grow its internal resources and pick up skills and experience that are unique to projects of an international scale. "This set of options has given us quite some momentum," says Orakzai. "It is helping us to become regional leaders. I have never seen an entity progress this quickly."

As a result of this development, some clients within the Abu Dhabi public sector have already adopted the model and Qatar recently announced the award of a programme management contract for its wastewater services programme.

"We have been discussing our experience with other clients," says Thomson. "The one thing I would like to see more of is devolved decision making.

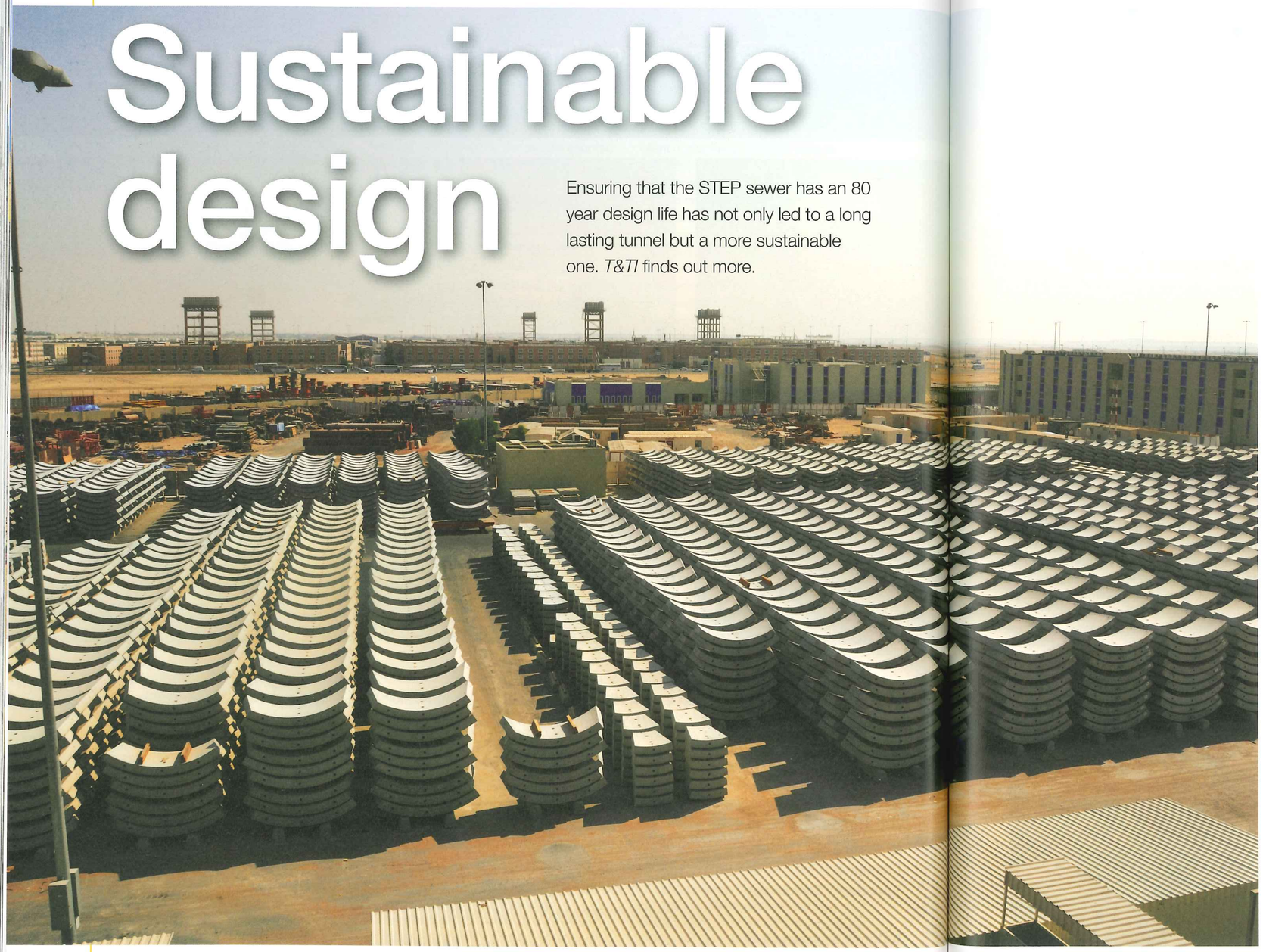
"I understand that because the economic situation Abu Dhabi has to be careful but once you start to come down from that it is important that you give the experts the full opportunity to use their expertise and trust them to tell you the best techniques and options and decisions to be made. That is very important."

Despite the complexity of the engineering challenge, Orakzai says that the management challenge is perhaps the greater of the two to deal with, but he is confident that the right approach has been taken considering the scale of the Step undertaking. Having introduced new contract forms and brought in large scale EPBMs for the first time, ADSSC is understandably under a lot of scrutiny from both its own residents and neighbours interested to see if the initiatives implemented will pay off.

Orakzai is clearly aware of this, but is not deterred by it either. "Pressure is definitely there," he says. "But if you can't stand the heat, get out of the kitchen."

Sustainable design

Ensuring that the STEP sewer has an 80 year design life has not only led to a long lasting tunnel but a more sustainable one. *T&TI* finds out more.



It is no secret that the ground conditions in the Gulf are among the most aggressive in the world. Salinity of the ground water is around four times that of the sea itself, at 10 to 12 percent, and many structures have learned the hard way that unless this is taken into account, concrete will not last long. Aware of this issue and determined to ensure its infrastructure lasts far into the future, Abu Dhabi Sewerage Services Company (ADSSC) has insisted on an 80 year design life for the 41km tunnel, and this has presented the designers with a huge challenge.

Danish firm Cowi is recognised as a world leader when it comes to development of concrete design and admits that meeting the design criteria has been demanding. "You see here 10-15 years old bridge piers with concrete spalling," says Cowi project director Peter Jackson. "Things don't last very long so when a client asks for 80 years this is really quite serious and very difficult to achieve."

The starting point for the segment design was to consider the design approach. As previous structures built in the 1970s in the region will testify, using international standards that do not take into account the local conditions or the required design life do not produce long lasting infrastructure. Fortunately Cowi had been involved in creating a new set of design criteria that place service life, in this case 80 years, at the heart of the design. Between 1996 and 1999 the firm, supported by the European Commission and 12 other partners, led a study to develop scientifically verified methods to design and evaluate concrete structures for durability or service life. The study was named the DuraCrete Project and the end result was a new computer based design tool for modelling service life of reinforced concrete.

From here Cowi, which is working for contractor Impregilo on contracts T02 and T03, began working up the design for the reinforced segments that form the primary tunnel structure. "The very high chlorides here are really the driver of the design," says Jackson. "Fibre reinforced concrete (FRC) of course is more durable in terms of chlorides," he says. The use of FRC is a key feature of the design as using steel fibres improves the inherent brittleness of the concrete, and what is more the tiny fibres are much less sensitive to corrosion than conventional reinforcement, which is usually made up of rebar cages.

A small amount of rebar is necessary at the longitudinal joints of the segments to counteract the high bursting stresses and ovalisation due to the soft surrounding rock. For a while this presented Cowi with a major problem as the concrete mix itself was not meeting criteria imposed on how chlorides diffuse through the concrete. As the levels of diffusion were too high Cowi had to specify stainless steel, which is less corrosive than ordinary carbon steel at the joints. This was much more expensive for the contractor, but durability came before price. "Initially we couldn't get the concrete to meet the chloride diffusion coefficient for the first nine months," says Jackson. "Then the mix was tuned and developed more and we finally got to this chloride diffusion coefficient. We have been very strict and Impregilo are very serious people and followed these requirements - even though it did mean spending millions of Euros on stainless steel," says Jackson.

Achieving this involved adjusting the volumes of materials in the concrete mix including the cement, fly ash and blast furnace slag. In the end the final mix replaced around 50 per cent of the cement with the ash and slag. "Sustainability flows out of this because actually the mixes we use for durability with a lot of fly ash and a lot of slag have lower embodied carbon dioxide. Durability and sustainability actually go together," says Jackson.

Left: A concrete segment factory supplies Impregilo and can produce 42 segments per day; Above: Herrenknecht Formwork has manufactured the moulds

Other measures required to ensure the long life of the tunnel include a high cover to the reinforcement of 70mm (compared to 35-40mm in standard design) and for the internal secondary lining a high-density polyethylene (HDPE) cover to protect the concrete from sulphate attack.

This is only required around the top 320 degrees of the tunnel because the potential attack comes from gases given off by the sewage organisms that create corrosive sulphuric acid. The bottom of the sewer, which will run submerged with effluent, will not be exposed and therefore will not need the liner.

Creating a concrete tunnel that will last for over 80 years has not been easy but Cowi and Impregilo say that working closely together has enabled the team to come up with a sustainable and durable solution for Abu Dhabi.

Fabrication

The precast concrete segment factory was set up specifically for contracts T02 and T03. Herrenknecht Formwork is supplying the moulds and the factory is therefore a joint venture between the German company and the local Commodore Contracting (CC). The dedicated batching plant and extensive laboratories ensure that the very stringent fibre reinforced concrete quality and durability requirements are met. Using 16 sets (ring) of moulds, CC produces 42 segment rings per day and has space reserved for the moulds for contract T03 when construction of the tunnel begins. To date CC has produced over 7,500 rings, or 70 per cent of the total, and have a stock of 2,500 rings.

Blaze the trail

Popular attention to the complexities and increasing size of modern TBMs often leads to overlooking the increasing number of functions that have to be performed with equipment just behind the cutterhead and shield. Maurice Jones reviews the functions housed on a TBM back up and how necessary equipment works together in limited space

It is virtually impossible for a TBM to achieve its maximum excavation potential without an efficient back-up (trailing gear) system to transport all the necessary ancillary equipment and, perhaps, carry out additional functions such as support work from the platforms it can provide. As a result a typical TBM back-up system is second only to the TBM itself in terms of complexity of interactions.

Back-up systems are drawn behind the TBM as it advances usually using hydraulic pull cylinders on the TBM and jacks working off either a segmental lining, if part of the design, or the resistance of gripper pads in hard rock tunnels. It is likely that some sort of braking system is also installed or, in the case of significant inclines (see feature, page 56) an anti-slip mechanism installed to prevent uncontrolled movements. The back-up system framework will be mounted on a chassis with rails or wheels with minimal friction to promote smooth movements, avoiding possible dangerous jerking.

A branch of Herrenknecht, Maschinen- und Stahlbau Dresden (MSD) has engineered many complex TBM back-up systems, arguably culminating in the 'worm' pipe bridge for Consorzio TAT for the Bodio/Faido section of the Gotthard base tunnel. The entire structure was 600m long and weighed nearly 2,000t. In addition to more normal TBM back-up duties, the worm's function is to recycle rock spoil into tunnel lining. Like the worm, each MSD back-up systems is unique as it is designed to meet the individual challenges of each project.

Below: Two trackbound spoil and materials cars on twin-rope haulage by Herrenknecht for the St Petersburg Metro 30-degree inclined access shafts

In addition to the back-up system, MSD also make segment handling systems (for the back-up and other locations in the logistics chain), TBM entry and breakout equipment at shafts, mobile lining structures and emergency systems.

Robbins usually makes its own back-up system with a few exceptions such as the Niagara system manufactured by Rowa. Others are made at the Company's facilities in Ohio, Shanghai and Guangzhou.

Packaging

Whilst each TBM back-up system tends to be unique as demanded by the characteristics of the project, the diameter of the tunnel is a common limiting parameter for all the equipment that has to be carried. Robbins senior designer Mike Anderson compares the situation to that of making a sausage. "The bigger the tunnel diameter, the shorter it can be," he says. "The components required are somewhat similar, and usually it's a packaging problem to get it all to fit. In some of the larger machines, it is not the packaging variable, but the structural strength that becomes the critical element."

Another metaphor for an efficient back-up system might also be the Rubik's Cube puzzle considering the number of necessary elements that have to be fit into a usually tight space in the right order. Anderson agrees that in general there is an optimal layout, with all equipment that is critical for TBM operation going in front, although not everything can be near the face. "Hydraulics, lubrication, some ground support and electricals go in that order, for the most part," says Anderson.

Sometimes, however, some elements have to be left behind, at least in the early stages of a drive. "Sometimes equipment can be left on the surface to be installed later," Anderson explains, "or there are other ways to launch the machine while the back-up is staged elsewhere. During an abbreviated start up, if the launch site is very small, the back-up decks may be staged on the surface, and the machine will be connected via umbilical cables.

The recent St Petersburg metro escalator access shafts presented many special problems to Herrenknecht as they were required to be only around 100m long, and at an incline of 30 degrees in soft ground. A single 21m backup was provided and the overall length of the TBM and backup was just 32m. The back up had to be installed in two stages due to the obstruction of the haulage winch house. The lack of space meant that electrical transformers for the hydraulics remained on the surface rather than be mounted on the back up.

Above: The three-deck Rowa back-up for the Robbins 'Big Becky' TBM on the new Niagara project. Note belt conveyor and ventilation duct

Invert

One of the trickiest places in any tunnelling operation, especially within the back-up area, is the invert. Anything can end up there to make a nuisance for smooth operations. Anderson reports that a means of tackling the problem was one of several innovations employed behind TBMs on the Parramatta project, Sydney, Australia.

It was a self-dumping invert muck cleaning system.

"This consists of a bucket that dumps rock and other materials that fall into the invert onto the conveyor," explains Anderson. "This was the first time such a cleaning systems was provided, and it has since been used on multiple machines such as the three hard-rock TBMs at the Karahnjukar project in Iceland."

Another frequent invert necessity is to line it, whether by a precast segment or by cast in situ concrete, as support for the tunnel and/or to provide a good transport surface. In the case of Parramatta, says Anderson, "The tunnel invert was concreted as the machine advanced, creating a road that rubber-tyre vehicles could then drive

on to carry muck out of the tunnel. The back-up was wide enough to allow two such vehicles to pass each other."

Another transport innovation on the Parramatta back-ups was turntable on a deck so that the crew manrider truck could drive up to it, unload its passengers, and then be rotated to drive back out of the tunnel.

Monitoring and control

Not only does the back-up system have to house the control cabin from where most of the TBM functions are operated, there also needs to be clear lines of sight for the reference survey laser beam. The arrangements may involve diversion of the beam around obstacles on the back-up system using prism stations.

Concrete spraying

In any cases where the ground is exposed after excavation, that is when using a gripper or partially shielded machine, it may be necessary to install immediate ground support unless the ground is particularly competent.

Sprayed concrete application using manual nozzles is rather impractical for immediate support behind a TBM especially if a heavily laden trailing back up is employed. Difficulties in obtaining the correct angles and distance of application, mess from rebound, and moving the pump and any mixing equipment can all make for an inefficient operation with reduced quality control. Circumstances may be a bit easier when lining the crown, particularly from a secure work-platform on top of the back-up system, providing a clear, safe area to carry out and assess the work. Although robotic spray systems can provide good quality control they are suited mainly to working in the clearer areas further behind the TBM and its associated trailing equipment.

More experience in dealing with poor ground immediately after TBM excavation has led to some suppliers combining the advantages of robotic spraying into the immediacy of the back-up location. Like most back-up systems, the equipment often has to be specially designed for the application although some standard principles can be followed.

Sika Aliva's TBM spraying robots, such as those used on the Gotthard base tunnel, provided immediate support in difficult, squeezing ground, that could cause more problems if left until the full TBM and trailing gear had passed through. The robot is mounted onto a frame in the shape of an arc and equipped with a geared rack and drive to provide peripheral movement at a suitable distance from the planned tunnel profile. This carries a telescopic arm with the articulated nozzle mounted on the end to achieve the necessary angles of application. Similar spraying robots for TBM drives have been used on the Karahnjukar hydroelectric project tunnels (the first TBM drives in Iceland) and many other TBM drives requiring 'immediate' support.

These early versions of TBM sprayed concrete systems were replaced about four years ago with models designed to minimise rebound, greater capacity and more reliability.

Sika Schweiz key account manager for TBMs in Europe, Andre Kortel elaborates, "We are doing a lot of TBM systems every year for shotcrete applications. We have these systems for L1, L2 (positions within TBM back up) or independent back-up solutions. The systems are produced by Sika Aliva in Switzerland."

Various forms of control of these systems are available whether manual or remote using cable or radio transmission. The working platform area is arranged so that the operator always has a direct view of the tunnel wall and spray nozzle.

Protecting other equipment on the back-up from concrete rebound can be an important issue. The new Sika Aliva machines, usually sited at position L2, about 50m behind the TBM face, have a central cylinder to protect the inner parts of the TBM back-up assembly, with 'curtains' at each end up to the tunnel wall to prevent dust transmission. The restricted rebound would normally be collected manually, says Kortel. "For automatic systems we do not have enough space and they are not working well," he adds.

Above: **The steep incline and winches restricted the length of the back up for Herrenknecht's TBM on the St Petersburg metro escalator shafts**

Such is the variation in the design of major TBM systems and their back-ups; the same has to be true of a related sprayed concrete system. "There is no standard possible," says Andre Kortel. "The concept is mostly the same but we are doing new engineering for every system. We have to adapt our systems every time to the dimensions of the TBMs. The size, length, width, speed and space conditions of the TBM are very important."

Other support

As mentioned before, it is common for rockbolts to be installed from the TBM back up, perhaps from a special platform in position 'L1' immediately behind the TBM face. The generally low headroom limits the size of the length of the bolts and the size of the drills used to install them. In some cases longer advanced ground reinforcement can be installed roughly longitudinally in 'fans' or arches. This may be combined with a doweling and/or grouting programme in poor ground.

Typically other support for a poor roof that can be installed from the TBM back up includes welded mesh sheets and steel ribs, but all are restricted to 130 to 180 degree arc at the crown.

In addition to the grouting measures that may be undertaken in exposed ground, TBM drives installing a segmental lining will need grouting facilities to fill the annulus and so distribute the ground loading over the lining's extrados. This will need grout storage or mixing facilities on the back up, controls and instrumentation to regulate flow and pressure. Pre-mixed grout may be kept in remixer cars temporarily sited below the back-up gantry. A possible alternative is to use pea-gravel instead of grout to achieve similar results as the material used in surface pipelaying. Kortel of Sika Aliva says the company is now working on equipment to backfill with pea-gravel behind the TBM, blowing the gravel into the annulus.

Spoil removal

Modern, high-capacity TBMs usually employ belt-conveyors to provide non-cyclical spoil removal capacity. That is, unless a TBM of a pressurised slurry type, in which case fairly large diameter pipes will run through the back-up system. In either case it is necessary to devise ways of storing extension capacity within the back-up system.

Slurry pipes will be connected by reinforced hose section that can unbend as the TBM advances until there is sufficient time available to connect another length of rigid pipe.

When employing belt conveyors some extension capacity to keep up with TBM can be built in by having a shorter belt conveyor from the TBM and through to back-up system or trailing gear to feed the main conveyor or, if used, spoil cars. The overlap between the two provides the extension capacity, although there will be a significant height requirement for the overlap and spoil chute. Whether or not a significant belt overlap is used, a main belt conveyor will still require extension capacity for longer advances. Specialist conveyor belt storage units on the return run can carry sufficient extension capacity for several shifts by having the belt wrapped round a series of rollers in 'concertina' fashion. In most cases underground the belt extension storage unit is housed and aligned horizontally due to space restrictions, but on the surface, or perhaps in caverns, vertical units can be used.

Marti-Technik has design, manufactured and installed an increasing number of spoil belt conveyor systems for TBM drives including the Tunnel de Choindez highway passage in the Swiss Jura; the Nant de Drance pumped storage scheme; the Koralm Tunnel in Austria; the Sparvo Tunnel in Italy and the Passante de Firenze for a new rail link in Florence. Some conveyors have been of considerable length including the 14.7km run for the Jinping II Ertan hydropower plant in China with a capacity of 1800t/hour, and the 6.4km (west) plus 4km (east), both of 550t/hour capacity for the Dragages-Nishimatsu JV on the Hong Kong West Drainage Tunnel.

The Robbins supply contract for the Parramatta rail project included not only the two Main Beam hard-rock TBMs and back-up systems, but also belt conveyor systems to the surface. These had to negotiate a series of horizontal and vertical with radii down to 400m.

Like MSD, a member of the Herrenknecht group, H + E Logistik specialises in conveyor systems, especially serving TBM installations. Typical belt storage capacity for extensions is around 500m per conveyor. The two tunnel belts used for current tunnelling in Brisbane, Australia, now called the 'Legacy Way' motorway tunnel, have 600m of belt storage each, with conveyor lengths of 2 x 4.5km. The belts are one metre wide for a 1400t/hour capacity each. The installation for the huge Sparvo Tunnel TBM in Italy has a capacity of 1200t/hour using a belt width of 1200mm. The total conveyor length will be 2750m.

The 30-degree inclines for new St Petersburg Metro escalator shafts demanded an unconventional spoil removal and supplies system belt conveyors and rack railways had to be ruled out by the conditions.

The design used two cars on twin-rope haulage for safety, with two winches. Herrenknecht designed the system, and other unusual equipment for the short, steep drives in soft ground (see *T&TI* March 2011, p.26).

Ventilation

The back-up system will need to provide space, at a minimum, for the incoming (forced) ventilation duct. There may also be a need for an extraction fan and filter unit in the case of expected dust generation as may be the case in an open TBM rock tunnel. Depending on the layout of the back-up system there may also need to be provision for local ventilation with additional ducts and perhaps fans, to cool any local 'hot-spots' such as motors and transformers, or to provide fresh air to housing such as the control cabin, refuge station or storage areas.

The main ventilation duct will have extension capacity built in as a flexible concertina housed in a metal cartridge through which air continues to flow. The folds of the 'concertina' are drawn out of the cartridge as the TBM advances.

Other services

In addition to spoil removal and transport equipment, other linear plant that will need periodic extension includes power cables, communications cables, water supply including fire-fighting range, and rail track for supplies and manriders.

As with conveyor belts and major pipework, there needs to be some form of flexible extension capacity to avoid frequent disruption of service due to installing new lengths of the service line. Specialist cable and hose reels are available to provide such capacity

Any necessary rail track extension can be facilitated by the traditional sliding California point system, but there is a growing trend to trackless (tyred) haulage for which attention to the invert may be necessary as described previously, but with no other extension work necessary.

Back up for difficult drives

When discussing the success or otherwise of TBM drives, the necessary back-up systems receive little attention and yet these multi-function units are vital to efficient tunnelling. Engineering manufacturer Rowa specialises in back-up and other support systems for unusual and difficult tunnelling circumstances, when efficient interaction of functions is even more vital

The steeply-inclined Aker Wirth TBM drive for expansion of the Linth-Limmern Linthal hydropower plant (KLL) in Switzerland is the latest in long string of tunnelling projects for which Rowa has custom-designed and manufactured back-up systems that integrate smoothly with the operation of a TBM itself, and 'outbye' systems, forming a critical link.

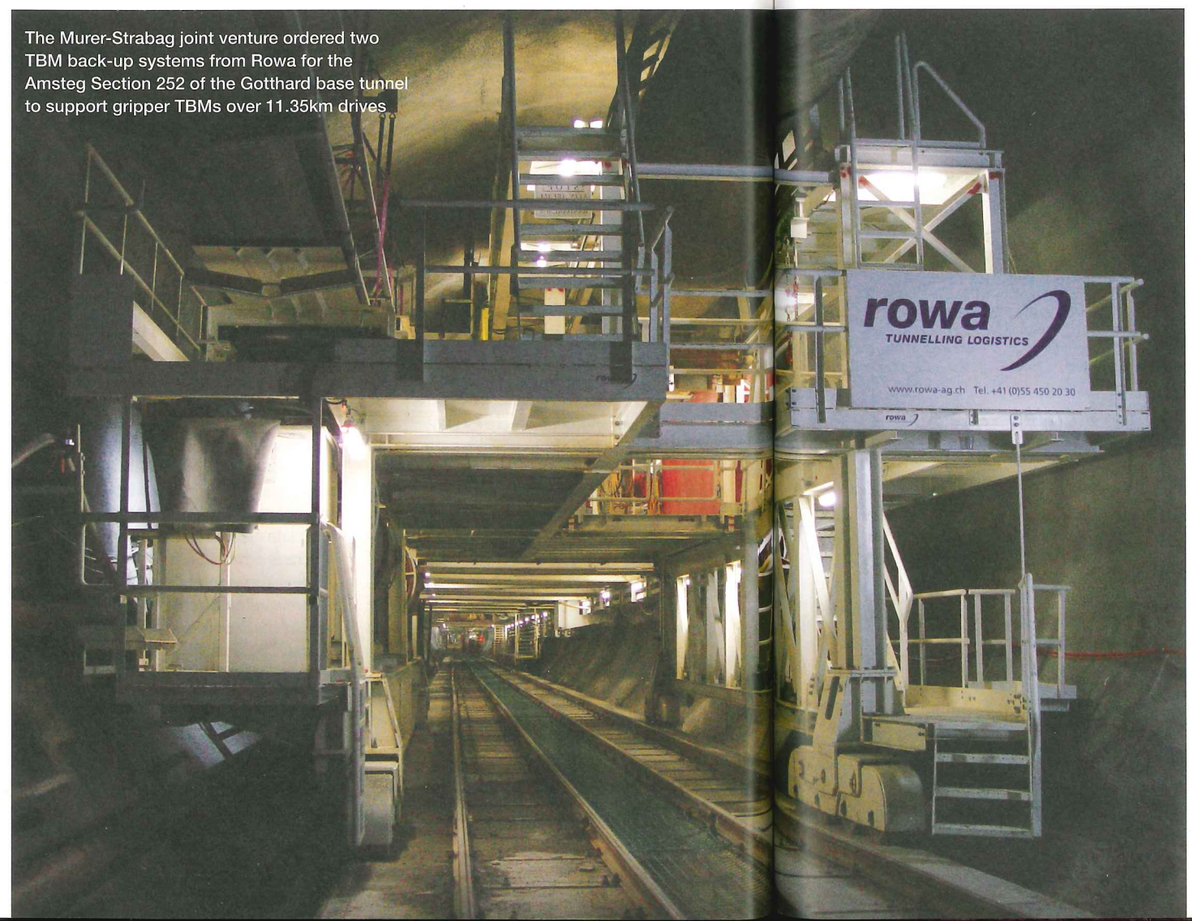
The upward incline of 24 degree from the launch site at Tierfehd over 4km of access tunnel to the power-station's new control centre and power plant caverns 1700m up in the mountain made particular demands on Rowa's designers working closely with their counterparts at Aker Wirth. The 8.03m-diameter Aker Wirth TBM required a 160m-long back-up system, which, obviously, could not be allowed to back-slide. Not only had the TBM and back-up system to cope well with the main inline, but also at the start of the drive the whole assembly had to negotiate a 300m-radius curve before the main drive.

As described in a previous article (see *T&TI* March 2011, pp.31-34), the expansion project will optimise the use of the existing facility and increase performance with an extra 1000MW of turbine capacity and 1000MW of pumping capacity, for pumped storage. The joint project owners are Axpo, the power station operator with 85 per cent, and the administrative region of Glarus with 15 per cent. The Arge AZL contractor joint venture is composed of Rothpletz, Lienhard + Cie, Wayss & Freytag Ingenieurbau, Baresel, G Lazzarini, Andrea Pitsch and Ragotti + Weber Bau.

AZL construction manager, Christian Ris, points out, "It has never been possible before to use such a big TBM to excavate such a steeply ascending tunnel."

The TBM is of the open-gripper type with x-pattern double bracings for better accuracy and reduced pressure on the tunnel walls. It was assembled at the access tunnel portal together with the back-up system.

At 8.03m the tunnel is the largest ascending inclined shaft excavated by a TBM, with the previous maximum set at a diameter of 6m.



The Murer-Strabag joint venture ordered two TBM back-up systems from Rowa for the Amsteg Section 252 of the Gotthard base tunnel to support gripper TBMs over 11.35km drives

Co-operation

The agreement between Aker Wirth and Rowa has enabled the contractor to order design, manufacturing, delivery, assembly and commissioning from one source. The severe gradient and large diameter means that the back-up system had to be specially designed to cope with unusual forces including both static and dynamic loads whilst working on the incline. Some idea of these forces can be gained when considering that the total weight of the back-up system to be held on the incline is 1500t, plus that of the TBM.

In addition to the TBM itself, the back-up systems include:

- Anti slip-back system
- Back-up modules using eight construction sites
- Apertures for installation of base (invert) lining segments
- Integrated supply train with hoist
- 'Consolidation L2' unit for sprayed concrete lining including mechanised rebound cleaning
- Conveyor belt systems
- Niche lining system

The anti-slip system supports the TBM etc between boring strokes and prevents it from back-sliding.

The Linthal TBM back-up system is integrated with a rail-bound supply and transport system with a 48t load capacity. This project was the first time that Rowa has constructed such a supply train, operated by a hoist system. The cable (or wire rope) is of 44mm diameter working on a 3.8km-long hoist system. The 2000kW hydraulic drive is mounted on a special steel frame within the back-up installation. Operational speeds are up to 4m/s. Other necessary features of the drive are safety brakes, overspeed and slack rope release.

The train itself has four flatbed cars that can be equipped with various modules. Suitable modules are available to carry supplies to the face or to the niche constructions, as well as for a 20-person manrider.

At the transport 'station' ('Back Up One') within the back-up the lining materials (i.e. sprayed concrete and segments) are handled using a travelling hoist carrying the material to its installation point. The segment hoist also carries materials to behind to anti-slip system of the back up. From there the material is carried on a car hauled by a horizontal hoist.

The same hoist car is used to supply materials to the conventionally excavated refuge niches and lay-by, and the installation of the final cast in situ lining.

The 'Consolidation L2' unit for sprayed concrete lining is situated within the back-up system separate from the TBM operations.

Size matters at Niagara

For the new Niagara hydroelectric-power tunnel, 10.4km long under the city of Niagara Falls for Ontario Power Generation's Sir Adam Beck generation plant enlargement in Canada, the back-up challenges were much more to do with size than inclination and altitude. The Robbins Main Beam hard-rock TBM chosen by contractor Strabag was of 14.4m diameter. The TBM's speed and diameter necessitated spoil handling facilities with a capacity of 1500t/hour. This resulted in a total spoil removal of 1.7Mm³ over the three years of excavation using a belt conveyor running through the 105m-long back-up system and on to the surface.

The design gradients are variable from an initial 7.8 per cent decline to reach the required horizon, after which the drive is practically horizontal for 7.4km, and then completing the drive with 7.3-per cent upwards incline. The size of the equipment required to move on these gradients placed large forces on both ramps of the back-up system.

Ground support activities simultaneous with excavation were also required since the surrounding rock was capable of swelling under high in situ stress. For some stretches of the tunnel the geological circumstances were even worse than this, requiring extra measures in which the back-up system played a full part. The initial rock support behind the TBM included a combination of welded steel mesh, steel ribs, rock bolts and sprayed concrete installed as the TBM advanced. This was followed by a cast in situ concrete lining further from the face, including a waterproofing membrane to prevent carried water causing the ground to swell more.

Ernst Gschnitzer, project manager for Strabag said, "Thanks to intensive co-operation and joint project development that began as early as the tender phase, it was possible to create a modern and highly mechanised logistics system which, despite initial difficulties, achieved an advance of over 18m per day once we had passed the 500m mark."

After 793m of excavation large blocks of the Queenstown shale started to fall from the crown in the open shield before rock support could be installed, sometimes resulting in some 3m of overbreak over the machine cutterhead.

Strabag designed a pipe spiling system to form an umbrella over the tunnel alignment using 9m-long pipes installed from the back-up. This limited the overbreak and progress was made through the next 500m of difficult ground.

A new support procedure was then adopted for all excavated ground, placing higher demands on logistics. Support material included rockbolts of 3.4m length, self drilling (IBO) rock anchors, steel straps, wire mesh and wire-reinforced sprayed concrete. The typical procedure was to excavate for just half a stroke, scale down any loose rock and then install rock bolts. Once the full stroke of 6ft (1.83m) had been completed more rockbolts were installed as well as the wire mesh, steel straps and a layer of sprayed concrete.

Rowa had installed extended, mechanised work platforms from the back-up system towards the back of the TBM to aid installation of the immediate support measures as described.

Future challenges on the Koralm Tunnel project

Working again with Aker Wirth, Rowa Tunnelling Logistics has recently been

Above: **Overhead belt conveyor for spoil through the Linthal back-up system (Photo: Rowa Tunnel Logistics)**

awarded a supply contract to produce the back-up system for the 32.5km-long Koralm Tunnel in Austria for the Koralbahn high-speed rail link between Graz and Klagenfurt in Styria and Carinthia. No details of the 160m-long TBM and back-up system are available as *T&TI* goes to press, but two will be required to work with the 9.93m-diameter telescopic TBMs on the 20km-long KAT Two central section of the project, due to start construction in October. These will form two single-track tunnels. The TBM and back-up system will have to be installed through the only means of access; a 60m-deep shaft near Deutschlandsberg.

An estimated 8.5Mt of spoil will be excavated, rock of which will be used to produce an estimated 1Mm³ of concrete to line the drives. This includes a stretch of NATM work as well as the TBM drives.

Gotthard

Other notable projects recently supplied by systems from Rowa include the Lot 851 of the Ceneri Base Tunnel in Switzerland for opening in 2019 (one back-up system for a Robbins 309 TBM in 2008 for the Consorzio Monte Ceneri - CMC), and section 252 (Amsteg) for the Gotthard Base Tunnel (two TBM back-up systems and an installation for excavation of cross-passages for the AGN joint venture of Strabag and Murer-Strabag (see *T&T Gotthard* Nov 2010 p.17). The two tunnels are linked on the same north-south trans-Alpine route for the project developers Alp Transit Gotthard.

The Ceneri Base tunnel drive is on a 4.8 per cent decline at 9.73m diameter, and 2.3km long. The back-up installation was designed with a raking system for the incline, and also for the installation of support including rock anchors, mesh, sprayed concrete and other steel if required to meet a TBM excavation rate of 26m per day.

In fact the back up systems were designed for twice that rate, using only minimal personnel.

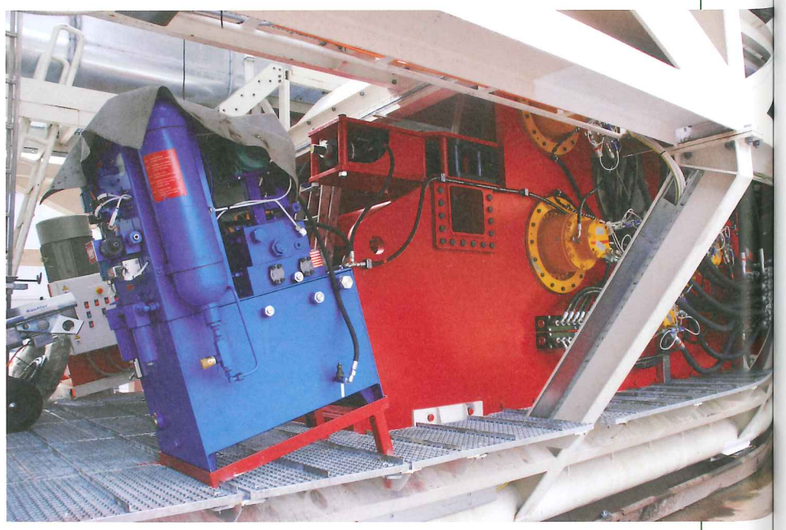
Additional equipment on the Ceneri back-up includes a vibrating screen to separate cobbles >150mm. Tunnel invert sealing was carried out completely separate from face advance.

For the Amsteg section 252 of the Gotthard, the contractor consortium Arge AGN Murer/Strabag ordered the back-up system directly from Rowa rather than through the TBM supplier but, according the Rowa, any interface problems could be managed without any difficulties and the system functioned perfectly. The contractor also had an experienced logistics partner available.

The Amsteg section is 11.35km long on a slight curve at twin-bore diameters of 9.58m and an incline of 4.08 per cent. Support measures such as sprayed concreting and invert construction were carried out from within the TBM back up. Spoil was removed by belt conveyor.

Material supplies were handled through the back-up system using a suspended monorail. This avoided rehandling between the supply train and the point of use or installation. With a double-track rail system together with the monorail supply route it was possible to continue invert construction to keep up with TBM progress. The back-up system also included a sprayed concrete 'robot' travelling longitudinally and capable of applying the sprayed concrete through a 360 degree arc onto the ground exposed by excavation.

Below: **Hydraulic anti-slip system and conveyor transfer point**



Lifting and crushing

Hitachi Zosen has developed special TBM backup equipment and rock crushing systems. Yasuharu Hanaoka of the corporation's engineering department, industrial business unit, and Katsuya Sasaki of the product development division, machinery and infrastructure headquarters, present this paper on automatic segment erection, boulder or concrete demolition and the labour-saving results

Segment erection is a field where work is typically undertaken in a narrow, dirty, dangerous space requiring hard labour as automation is relatively new. However, as large-diameter shield use has become more widespread, the requirements for safety, rapidness and quality improvement has increased. Thus, the technical study of an automatic erection system was accelerated, and the method was experimentally adopted by various projects. As a result, the technology progressed significantly, and rapidly reached a stage of practical use and popularisation.

Hitachi Zosen (Hitz) started the development in 1989 and delivered the first machine for the Trans-Tokyo Bay Highway in 1994 where the machine out performed expected advance rates.

Hitz subsequently obtained orders for three 12m-diameter machines, and finished the projects successfully.

Shibukawa Reservoir

The series of processes from feeding the segments to fastening the bolts was automated on the Shibukawa Reservoir 12.34m machine. This automatic erection system has a positioning device composed of seven axes, all of which are precisely servo-controlled in order to exactly position the segments in the desired spatial location. It can assemble segments weighing approximately six tonnes at the end of the system, with a precision of ±1 to 2mm.

The system is composed of: an 'erection system' that assembles and fastens segments along tunnel walls, a 'segment feeding system' that feeds the erection system and a 'carrying system' that lifts the segments and lowers them into the segment feeding system. A 'bolt and nut supply system' feeds the erection system with nuts and bolts for fastening, and a 'shield jack' presses the segments.

Since the construction route of the projects includes a sharp, 120m-radius curve, a manual type of stock conveyor is adopted. However, in other projects, an automatic stock conveyor can be used to transfer the segments directly to the segment feeding system. In order to realise a high speed, each system performs its role in parallel as much as possible without

Table 1: Results of erection time reduction

Item	Tokyo Bay 14.14m	Shibukawa Reservoir machine' 12.34m shield
Average erection time per piece	7.4 min	4.2 min
Average time reduction per piece	–	3.2 min (-43%)
Erection time per ring	81.4 min (11 pieces)	42.0 min (10 pieces)
Erection time reduction per piece	–	39.4 min (-48%)

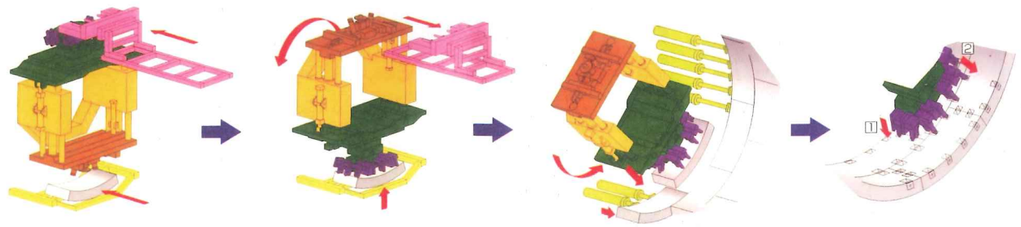
Below: **Figure 1, the automatic segment erection system sequence**

Bolts and nuts supply
1) Bolts and nuts supply system pushed out (feed bolts and nuts for one segment)
2) Segment feeding system pushed out

Segment feeding
1) Bolt and nut supply system returned
2) Erector turned 180°
3) Segment gripped

Positioning and pressing seals
1) Moved to erection position by sensor
2) Seals pressed circumferentially and axially

Fastening bolts
1) Fastening circumferential joints
2) Fastening axial joints



causing interference. In positioning, the system learns the erection position data of the previous segment to improve precision of rough positioning (using no sensors). This allows a great time saving by minimising sensing cycle time. The segments in this example consist of a ring with an outside diameter of 12.1m, inside diameter of 11m and a width of 1.2m, divided into 10 pieces. Key segments are of a wedge type inserted axially.

Table 1 on page 61 shows the time ratio compared with our Tokyo Bay machine. The Shibukawa Reservoir machine showed a significant time reduction due to various improvements.

Improvements achieved by this system:

- Improvement of rigidity and weight reduction of components to increase speed and improve precision
- Reduction of failure ratio by simplifying structure, reducing adjusting points and improving maintainability
- Time reduction by enlarging application range of parallel action
- Minimising sensing by adding a learning function for rough positioning

Automation facility for trailing work and gear

Automatic segment carrying system

The automatic segment carrying system conveys segments from the carriage to the erection system and is composed of an automatic travelling system, and a lifting system with an automatic lifting device. A four-point lifting chain block is used and each stock wagon contains segments for one ring. Since the loading to the stock wagon and the transfer from the stock wagon to the erection system is automated, and the segments are automatically lifted to be ready for the next erection, the cycle time can be reduced. Simplified systems for slurry shield machines are also available.

Segment unloading system

This is a system for loading and unloading the segments. The segments are lifted from the segment trains using forks on both sides, enabling a speedy unloading time. This system is especially effective on tyre-driven carriages, where alternate traffic is impossible, as it plays the role of a segment storing system. The forks are inserted and retracted by hydraulic cylinders, and are elevated by an inverter drive electrical jack that synchronises the right and left forks. Attaching an automatic guide vehicle (AGV) to the segment carriage enables this linked action.

Segment re-tightening system

Segment bolt re-tightening work requires hard labour in an unstable workplace. It also requires increasingly elevated work as the tunnel diameter increases. This work can be fully automated with the use of a tightening robot.

This robot is fitted with a multi-articulated arm, with a tightening system installed on elevating systems that are mounted on the right and left sides of the self-propelled carriage. The bolts are automatically found and tightened by the numerical data entered beforehand, as well as sensors. The tightening is performed by an electric servomotor that enables accurate torque control and automatically records various operation data. The multi-articulated arm can handle a load of 500kg at its end, and is versatile to cope with a varying tunnel diameter.

With a remote control bolt re-tightening system, an operator performs re-tightening work while viewing video camera images.

Vertical earth-lifting screw conveyor system

The existing crane, a vertical belt conveyor, a pneumatic conveying pipe or continuous bucket system is used for lifting out excavated materials. However, intermittent discharge, a range limitation of applicable soil and limitations of the lift head have been the main problems where these systems have been employed. In order to deal with the requirements for the construction of deeper tunnels, and space saving for vertical shaft construction as well as speeding up the work, a new screw-type earth lifting system has been developed.

Advantages

- Using a ribbon screw that has no central shaft to achieve high efficiency by compression
- Rotating support ring and a drive unit is equipped at screw peripheral, and screws are connected in series to lift and convey earth smoothly. No theoretical limitation of lift head exists
- No adverse effect on environment because of closed and compact setup
- Insertion of a fixing shaft enables further efficiency improvement
- Capable of continuously discharging earth by forming a material seal to keep the pressure

Demonstration experiment in factory

The screw diameter and the lift head are 300mm and 5m respectively. Any number of screws can be connected straightly because the support sections coupled with a drive shaft are installed at the top and the bottom of the system.

The experiment results showed that the system is applicable to conveying a range of substances.

Application

The system has a wide range of applications in addition to the discharge of excavated materials during tunnel excavation. It has uses dealing with waste materials, waste food, sludge, and ore as well as the continuous discharge of surplus soil from a pneumatic caisson.

Development in the future

Table 2, below shows the specifications of this system. Through validation tests on the future site the system will be completed as a commercial product that can be applied to various industrial fields.

Table 2: Specifications

Model	HS–250	HS–400	HS–600	HS–800
Casting outside diameter	267.4	406.4	609.6	812.8
Screw outside diameter Db (mm)	250	385	580	782
Screw speed (min^{-1})	50~76	40~60	33~50	28~43
Coveying rate (m^3/h)	11~17	33~49	93~141	193~297
Power consumption (kW) (coveyer length = 20Db)	7.5~11	18.5~30	50~75	100~150

Rock crushing system

The blasting of rocks with explosives is widely carried out because explosives are cheap and provide a high crushing force. However, problems related to safety are encountered when explosives are used. Therefore, in Japan, explosive products and their use, storage, and transportation are governed by the Explosive Control Law. Furthermore, residents of areas near construction sites rarely permit the use of explosives.

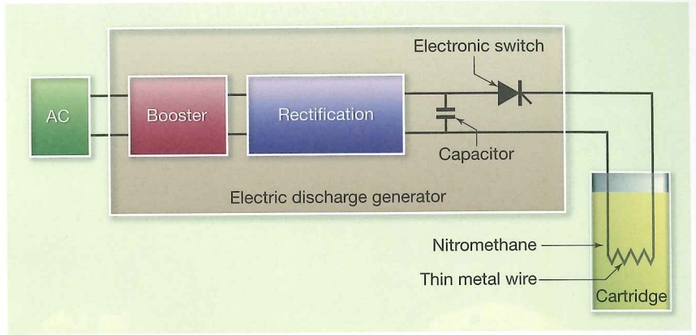
Therefore, a new and practical method that can safely generate a crushing power equal to that achieved by using explosives, is expected to become of practical use. Hitz has developed an effective non-explosive method, the 'Electric Discharge Impulse Crushing System' (EDICS) (K. Sasaki et al, 2011). EDICS has been used on many construction sites for the demolition of reinforced concrete structures and the splitting of rocks and boulders.

Regarding tunnel excavation, EDICS has been used for widening the tunnel section, excavating vertical shafts and splitting boulders in TBM chambers.

It became apparent that EDICS is a useful tool for TBM excavation.

Fundamental EDICS

The EDICS system uses a commercial power supply or a power generator and consists of an electric discharge generator, a cartridge to generate impulse force, and cables. The electric discharge generator can generate a pulse of up to 3,000V. The diameter of the cartridge ranges from 10 to 30mm, and its length ranges from 50 to 100mm. The length of the cable connecting the electric discharge generator to the cartridge ranges from 40 to 200m. The electrical energy stored in the capacitor that is charged from 1,500 to 3,000V, and is included in the electric discharge generator, is supplied to the cartridge through an electronic switch. The generating force produced by the reaction in the cartridge is slightly less than that produced by explosives. In Japan, the EDICS is being increasingly used for splitting reinforced concrete structures and excavating tunnels and deep foundations.



Above: **Figure 2, circuit diagram showing configuration of the EDICS**

Figure 2, above, shows the configuration of the EDICS. The electric discharge generator converts commercial AC voltages into DC voltages in the range of 1,500 to 3,000V, and the electrical energy is accumulated in the capacitor. The electrical energy stored in the capacitor is supplied to the cartridge within several hundreds of microseconds through a semiconductor electronic switch. A capsule-type cartridge is used.

The cartridge has a pair of electrode lead wires, through which the electrical energy is supplied. The cartridge contains nitromethane and a thin metal wire that connects the two lead wires. When electrical energy is supplied from the electric discharge generator to the cartridge, the thin metal wire evaporates within several microseconds, and the temperature and pressure increase due to the plasma that results from the evaporation of the metal wire. As a result, the nitromethane in the cartridge burns and a large force is generated. This causes the target to split.

Application of EDICS

The EDICS can be easily used in urban areas because it is non-explosive, and the only effects on people in the surrounding area are slight and momentary vibration and noise. This procedure runs as follows: first, the borehole is created; second, the cartridge is placed in the borehole and the borehole is stemmed; third, the cartridge is connected to the electric discharge generator; fourth, the cover is installed; fifth, the electrical energy is supplied to the cartridge, and the splitting fragments and reinforcing steel are removed. One cycle could be completely in approximately one hour.

Above left: **Preparing to apply EDICS to boulder;** Left: **After two applications the boulder was shattered completely**

In one case, a shield machine had been stopped by a 0.5m boulder blocking its discharging pipe. In this case, EDICS was used to split the boulder, clearing the blockage. In this case, using EDICS was cheaper, safer and quicker than any other existing method.

EDICS has been used for tunnel widening works near an existing tunnel. In one case, an existing road was in use nearby, therefore excavation of the tunnel faced vibration restrictions of a maximum 50mm/s at 5m from blasting point.

It is difficult to apply for explosives because of the high vibration generated. EDICS, which generates relatively low vibration, was applied to widen this tunnel resulting in vibration levels under the 50mm/s limit.

Conclusion

The EDICS is a practical technology for splitting rocks by generating force that is slightly smaller than that of explosives. Since it is a safe and efficient technology, its use is steadily increasing in Japan. Now Hitz is trying to get certification to use EDICS in the US and other countries.

Moreover, it is already used to assist in various tunnel excavations.

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Specific energy of excavation in detecting tunnelling conditions ahead of TBMs

The concept of the 'specific energy of excavation' is not new, dating back to the 1960s, but an innovative application of its main component during trials in TBM tunnels in Spain showed that it can be used effectively to detect changes in tunnelling ground conditions based on real-time recording of the machine performance as construction proceeds, as the authors explain

Authors

This article is an edited version of the paper 'The Specific Energy of Excavation as an Aid for Detecting real-time Changes in Tunnelling Conditions ahead of TBMs' by Prof Richard Z T Bieniawski of Bieniawski Design Enerprises, Arizona, US and by Benjamin Celada, Isidoro Tardaguila and Alejandro Rodrigues of Geocontrol, Madrid, Spain.

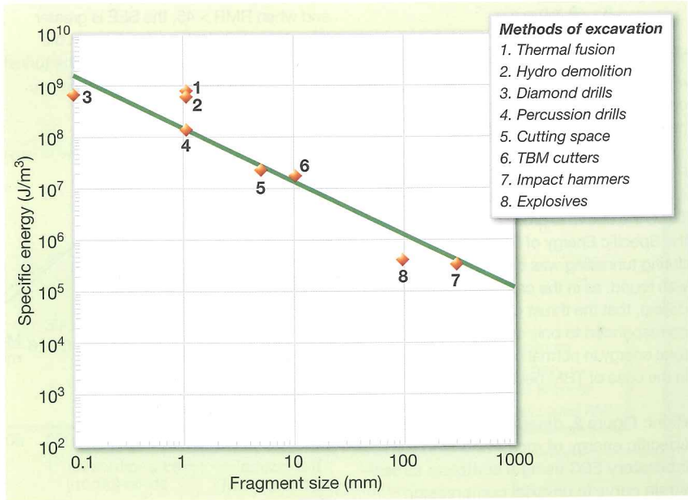
The specific energy of excavation (SEE) is defined as the relation between the energy involved during the process of excavation, expressed in megaJoules (MJ), and the volume of ground excavated in m^3.

The concept of the SEE has been utilised for many decades to assist in assessing the efficiency of the drilling processes and excavating in rock masses. First reported in the petroleum industry (Teale, 1965), it is a parameter that can be determined in real time from the data recording the performance of a drilling machine or a TBM. In addition, what makes this parameter particularly attractive is its correlation to the mechanical properties of the rock mass (Acaroglu et al, 2008).

During the past three years, Geocontrol of Madrid, Spain, conducted investigations with a partial grant from the Center for Industrial Development (CDTI) of Spain utilising the SEE to characterise rock masses for use in TBMs. As a result of this effort (Geocontrol, 2011) this article presents new findings to assess the excavation process and estimate the quality and other key characteristics of the rock mass as the TBM progresses.

Dependency

The specific energy of excavation depends on rock mass condition and on the excavation process. Cook and Joughim (Cook and Joughim, 1970) performed tests examining the various methods of excavation in quartzitic rock masses found in South African gold mines, the uniaxial compressive strength of which could exceed 200 MPa. They measured the SEE by each method studied as a function of the size of rock fragments produced during the various processes of rock breaking. The results are shown in Figure 1, below.



Right: **Figure 1, correlation between the energy consumed by various methods of excavation and the size of rock fragments in mm**

This figure leads to the important conclusion that the SEE is related exponentially to the size of rock fragments produced during the rock breaking process, and that excavation by explosives consumes the least amount of energy among the methods studied. TBM boring falls in the middle of the range.

Calculation

The Specific Energy of Excavation can be calculated using the expression by Teale (Teale, 1965) who was the first to publish research about the use of the Specific Energy in the process of drilling large diameter samples of rock. He proposed that the Specific Energy of Drilling (EEP) is calculated using the following expression:

$$EEP = \frac{F}{A} + \frac{2\pi\,\omega\,T}{A\,u}$$

where:

- EEP is the specific energy of drilling (in MJ/m³),
- F is the total thrust (in kN),
- A is the area of drilled (in m²),
- ω is the speed of rotation (in rev/s),
- T is the applied torque (in kNm),
- u is the drilling advance rate (in m/s).

The first part of the above equation corresponds to the energy proportional to the thrust imposed while the second part is the energy consumed for drill bit rotation.

If one uses the concept of specific penetration for each revolution, $P = \frac{u}{\omega}$, then the above expression is:

$$EEP = \frac{F}{A} + \frac{2\pi\,T}{A \times p}$$

Teale (1965) has shown that $\frac{F}{A}$ represents only one per cent of the total energy and thus this can be neglected for practical purposes.

During field trials by Geocontrol in the Pontones Tunnel in Spain (2009-2010), excavated by a Herrenknecht single-shield TBM, the above expression was tested and the Specific Energy of Excavation (SEE) during tunnelling was calculated. Again, it was found, as in the case of large diameter drilling, that the thrust component corresponded to only one per cent of the total energy in normal conditions. However, in the case of TBM being trapped, this component can amount to 30 per cent of the energy; a figure that can no longer be reasonably neglected.

Accordingly, for tunnel excavation by TBMs, it can be stated:

$$SEE = EE_{THRUST} + EE_{ROTATION}$$

In this equation, the first component (EE_{THRUST}) represents the specific energy consumed to advance the TBM (which as indicated is about one per cent of the total in most instances) while the second term ($EE_{ROTATION}$) is the specific energy to rotate the cutterhead, which actually produces the excavation in the rock mass.

Lab tests

The specific energy in the process of rock fracture in compression can also be determined in laboratory tests The specific energy during the process of rock fracture in compression may be determined in laboratory tests from complete stress-strain curves obtained on rock samples tested in high stiffness, servo-controlled presses; the value of the specific energy in compression tests (EEC) coincides with the area under the curve along the axis of strain, as illustrated in figure 2, below.

Lab/site comparison

The specific energy of excavation in situ is much greater than the specific energy of fracture in a laboratory test. From the data obtained during the TBM excavation in the Pontones Tunnel in Spain, the specific energy of excavation (SEE) was calculated for various values of the rock mass quality (RMR) which led to the findings that when RMR < 35, the SEE is less than 10MJ/m³ and when RMR > 45, the SEE is greater than 32MJ/m³. At the same time, in the tests on intact rock samples from the tunnel rock formations in uniaxial compression, using a servo-controlled machine, the values of EEC (lab) were 10 to 20 times less than those of the SEE in the field. Such results seemed contradictory. After all, due to the fact that a rock mass includes discontinuities and rock material does not, this suggests that the specific energy of excavation to break up a rock mass should be less than that necessary to fracture rock material. A probable explanation of the results obtained might be that the process of rock fracture in compression is more efficient than that of excavation by TBM.

SEE analysis

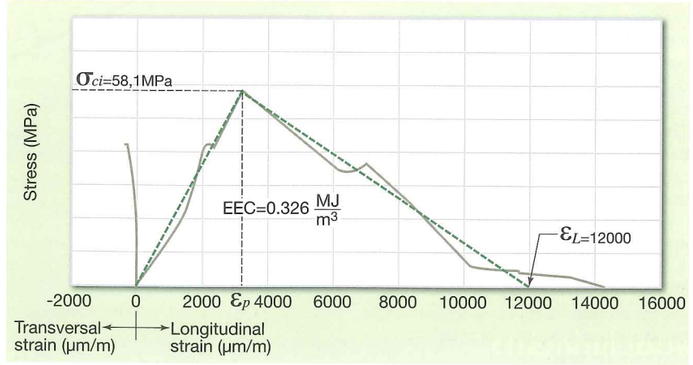
To control the work of a TBM it is necessary to analyse the specific energy of excavation by its principal components. The specific energy component due to the rotation of the cutterhead (EEG), under normal conditions, is responsible for 99 per cent of the energy used during TBM excavation. In fact, it is made up of three terms:

$$EEG = EEG_r + EEG_f + EE\varepsilon$$

EEGr is the specific energy required to press the TBM cutterhead to the tunnel face. In normal conditions, EEGr consists of 57-77 per cent of the total SEE; the higher values corresponding to the higher RMR ratings of the rock mass excavated.

EEGf is the specific energy used to rotate the cutterhead against the terrain previously indented by the TBM cutter. In normal conditions, EEGf accounts for 31-41 per cent of the total specific energy of excavation SEE. Contrary to the EEGr, the higher values of EEGf correspond to much lower ratings of RMR.

The term EEε entails the rest of the specific energy of excavation, which is spent on activities relating to the action of the cutterhead. These constitute about two per cent of the total; and thus negligible.



Right: **Figure 2, determination of the specific energy of rock fracture in laboratory EEC using a complete stress-strain curve in uniaxial compression**

In normal conditions of the functioning of the TBM, both EEG_r and EEG_f maintain the proportion of the total energy as indicated, however when the rock mass conditions change significantly and become more difficult, the proportion of EEGr approaches 77 per cent of the total energy expended, and at the limit when the terrain just cannot be excavated, it reaches 100 per cent.

In the opposite case, when the rock mass loses its strength and becomes unstable at the tunnel face, the cutters have great difficulty in being effective, then the other component EEGf amounts to 100 per cent of the total energy.

For the purpose of assessing and maintaining efficient functioning of the TBM, an index of efficiency of excavation (IEE) becomes very useful, and can be calculated in real-time of TBM operation, based on the parameters recorded during the advance of the machine, which are typically obtained automatically every ten seconds. These, limited by contract on the trails, are thrust (kN), torque (kNm), rotational speed (rev/min) and advance rate (m/s).

Based on the experience gained and observations during the field trials, the index of efficiency of excavation defines the following ranges of TBM functioning:

- If IEE < 0.25, the TBM runs the risk of being immobilised at the cutterhead due to instabilities at the tunnel face;
- If 0.25 < IEE < 1.75, the TBM works normally;
- If IEE > 1.75 the TBM has great difficulties in excavating the terrain due to the high strength and abrasivity of the rock mass.

Depending whether the IEE is lower or higher than one, EEGr and EEGf are calculated according to the following:

if IEE < = 1:

$$EEG_r = \frac{4.}{5}\,Kt.\frac{fc}{1000\,\mu}$$

$$EEG_f = EEG_{Teale} - EEG_r$$

if IEE > 1

$$EEG_r = \frac{1.}{5}\,K_i.cec\frac{fc}{1000\,\mu}$$

$$EEG_r = EEG_{Teale} - EEG_f$$

Right: **Figure 3, correlation between the Specific Energy of Excavation and RMR at the front of the TBM. Data of 270 values from three tunnels.**

where:

- EEG = total specific energy of rotation after Teale (1965)
- EEGr = specific energy of rotation when advancing the cutterhead (in MJ/m³)
- EEGf = specific energy of rotation due to friction when turning the cutterhead (in MJ/m³)
- Fc = thrust of the cutter (in kN)
- Coefficient $\mu = \sqrt{\frac{p}{d}}$ according to Sanio *(Sanio, 1985),*

  where p is penetration per revolution and d is the diameter of the cutter (in mm).

- Kt = Constant characteristic for a TBM type: $\frac{N}{R\sqrt{d}}$ [1/m²]

  where N is the number of cutters and R is the radius of the cutterhead, m.

- Ki = Constant characteristic of the excavation process by TBM: $\frac{100EEG}{Fc/\mu}$ [1/m²]

  where Fc is thrust per cutter (in kN).

- cec = Coefficient of cutter efficiency

$$cec = \frac{1}{IEE}$$

RMR related to SEE

The RMR of the rock mass at the TBM face may be estimated as a function of the specific energy of excavation.

Based on the data from two tunnels in Spain (Pontones Tunnel II and Sorbas Tunnel I), as well as one (Los Bronces Tunnel) in Chile, the following correlation was obtained, as depicted in figure 3, below.

This figure allows one to estimate the values of RMR of the terrain excavated at the front of the TBM with an error of only +/-5 points using the following correlation:

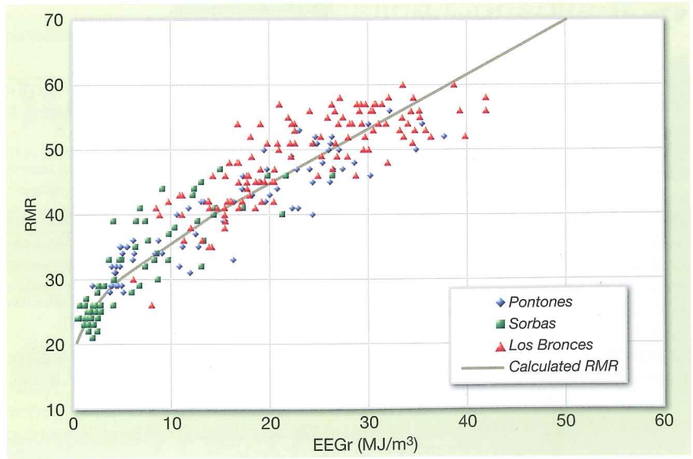
$$RMR = \frac{5.Ln\,(EEGr/80) - 100}{Ln\,(EEGr/80) - 1}$$

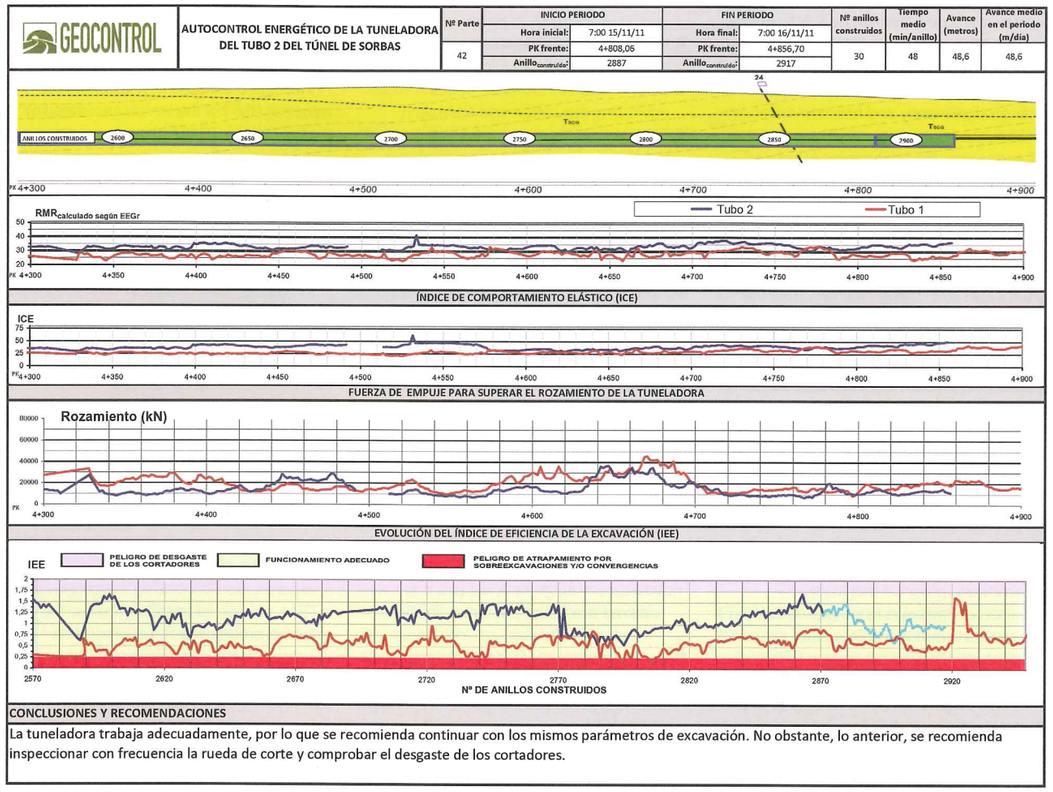
r^2 : 0,86 1< EEGr (MJ / m³) < 40

An estimation of the rock mass quality RMR of the terrain excavated in front of the TBM is most useful as a warning of approaching adverse conditions and, if necessary, to allow selection of the appropriate rock mass reinforcement which can be installed from the TBM as is done with open-type TBMs.

Real-time conditions

The parameters controlling the progress of a TBM, provide information on how the machine progresses in real-time; thus developing vital data which can be used as a guide to optimie TBM advance. A similar methodology, although less precise at the time, was used during the construction of the well-known Guadarrama Tunnels in Spain (Tardaguila & Suarez, 2005).
As result of this project, a monitoring system called 'Auto-Control of TBMs by energy parameters' (ACT) has been developed. This system allows, in real time, recording of the following parameters:





Above: **Record of information in real time obtained during TBM excavation of the Sorbas Tunnel in Spain**

- RMR, calculated from EEGr;
- Index of elastic behaviour (ICE), after (Bieniawski et al, 2011);
- Thrust to advance the TBM (in kN).

As an example, Figure 4, above, presents the data automatically recorded in real-time at the Sorbas Tunnel, based on the ACT installed in the TBM.

The chart (Figure 3) shows EEGr correlates closely with RMR. As both can be automatically recorded during TBM operation and expressed as the efficiency index IEE, any significant change in the index can alert the operator to a possible change in the rock mass quality RMR – thus warning of adverse conditions.

Conclusion

The concept of the specific energy of excavation has been revised and further developed for use with TBMs demonstrating a correlation between its main component of EEGr (the specific energy of rotation) and also rock mass quality (RMR).

An index of excavation efficiency has been introduced based on field trials of three tunnels in Spain over the past three years. Serving as a warning of adverse conditions, any significant change in the index in real-time can alert the TBM operator to a possible change in the rock mass quality.

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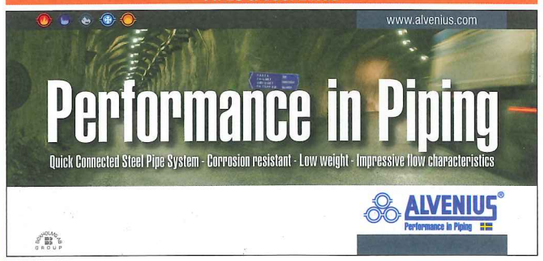

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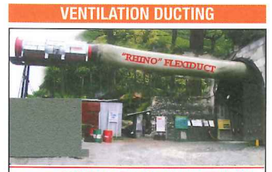

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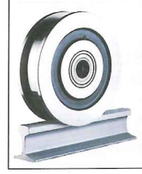

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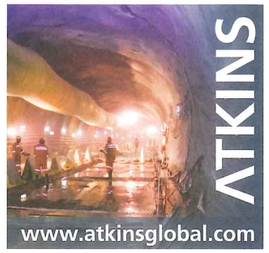

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BRITISH TUNNELLING SOCIETY

dates & events

21 - 22 FEBRUARY 2012
Fire Protection and Safety in Tunnels Asia, Singapore
With Asia having some of the longest tunnels in the world and some of the most rapid developments occurring globally this is the best platform to uncover current and future projects across the region and pinpoint the best strategies to ensure fire design is implemented accordingly. The conference will also include a site visit to a Singapore tunnel. More information is available at http://www.arena-international.com/fpstasia or email events@arena-international.com

14-16 MARCH 2012
ISTSS 2012, New York, USA
Forum with the themes of risk and security, human behaviour, passive fire protection and construction, active fire protection & fire fighting, ventilation and fire dynamics. The focus is shifting more and more towards security, with new the terrorist threats and the focus on how to solve these problems increasing. Organised by SP Technical Research Institute of Sweden - Fire Technology. For more information see www.istss.se, email info@sp.se or tel.: +46 10-516 50 00

20-22 MARCH 2012
3rd Brazilian Congress on Tunnels & Underground Structures & Intl Seminar 'South American Tunnelling', Sao Paulo, Brazil
At Centro Fecomercio de Eventos. The event will include 11 topics and be run with an exhibition and technical visits to World Cup sites etc. Now more than 70 subscribers reported. Two days will be reserved for a refresher course and training. Contact Executive Secretariat, Acqua Consultoria on tel.; +55 11 3868 0726, email 3cbt@acquacon.com.br or see www.acquacon.com.br/3cbt.

22-23 MARCH 2012
Intl Sym 'Practices & Trends for Financing & Contracting Tunnels & Underground Works', Royal Olympic Hotel, Athens, Greece
Organised by the Greek Tunnelling Society and ITA endorsed. Contact GTS on tel.: +98-21-88630496, email bakojon@otenet.gr or see www.tunnelcontracts2012.com

27 - 29 MARCH 2012
INTERtunnel 2012, Turin, Italy
The tenth edition will be staged at the Lingotto Exhibition together with Expo Ferroviaria. Italy's only regular exhibition on tunnelling technology but also with great international input. Italy claims the greatest number of tunnels in Europe and also has cross-border projects between Turin and Lyon, France, and also the Brenner Base Tunnel to Austria. Alongside Expo Ferroviaria rail exhibition. For more information email: intertunnel@mackbrooks.com or tel. Arianna Rosini on telephone +44 (0)1727 814 400

12-14 APRIL 2012
UnderCity 2012, Dubrovnik, Croatia
Colloquium at Hotel-Congress Center Valamar Lacroma on using underground space in urban areas in south-east Europe. Organised by ITA Croatia. Contact Tanja Rabar on tel.: +385-51-410-447, email tanja.rabar@hubtig.com or see www.undercity2012.com.

16-21 APRIL 2012
Intermat, Paris-Nord Villepinte, France
International exhibition of equipment, machinery and techniques for the construction and building materials industry. Companies registered so far include Casagrande, Cifa, Herrenknecht, Jean Lutz, Montabert, Peri, Robit and Sandvik. Enquiries to Maryvonne Lanoe or Maud Carcy on maud.carcy@comexposium.com, tel.: + 33 (0)1 76 77 11 93 or see www.intermat.fr

24 - 26 APRIL 2012
3rd Intl Conf on Shaft Design & Construction, London, UK
Organised by the Mining Technology Division of the IMMM and the BTS at 1 Carlton House Terrace. The scope includes all areas of design and construction of both civil engineering project and mine shafts. Contact Paul Harris at IOM Communications by email paul.harris@iom3.org, tel. +44 (0)20 7451 7302 or see www.iom3.org/events/sdc2012.

18 - 23 MAY 2012
World Tunnel Congress WTC 2012 & 38th General Assembly of the ITA, Bangkok, Thailand
Organised by the Thailand Underground & Tunnelling Group (TUTG) of the Engineering Institute of Thailand with the ITA, the theme is 'Tunnelling & Underground Space for a Global Society.' For more information email: secretariat@wtc2012.com or visit www.wtc2012.com

29 MAY - 01 JUNE 2012
SSCS - Numerical Modelling, Strategies for Sustainable Concrete Structures, Aix-en-Provence, France
Organised by the Association Francaise de Genie Civil (AFGC). Contact Nadget Berrahou-Daoud on tel.: +33 1 44 58 24 29, email afgc@enpc.fr or see www.afgc.asso.fr

24 - 27 JUNE 2012
North American Tunneling Conference (NAT), Indianapolis, Indiana, USA
UCA's biannual conference, which has continued to grow each year with more exhibits, technical sessions & attendees. More information regarding housing and registration will be available at http://uca.smenet.org/ in spring 2012

18 - 21 SEPTEMBER 2012
Eastern European Tunnelling Congress, Budapest, Hungary
The Hungarian Tunnelling Association is organizing the 1st Eastern European Tunnelling 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/

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

7 - 9 NOVEMBER 2012
13th World Conference of ACUUS, Singapore
The Associated research Centers for Urban Underground Space (ACUUS) presents 'Underground Space Development – Opportunities and Challenges' to focus on new opportunities in developing the urban underground space as part of sustainable development, and the issues that planners, developers, and engineers face. More information at http://www.acuus2012.com

BRITISH TUNNELLING SOCIETY

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.

16 FEBRUARY 2012
Chile Mine Rescue
A joint meeting with the MinSouth local society of the Institute of Materials, Minerals and Mining. Brian Robinson of Mine Rescue will describe the famous rescue of the 33 Chilean Miners in 2010 and ask whether we are prepared for a similar event in the UK.

15 MARCH 2012
Report from the BTS Compressed Air Working Group
Presentation by Dr Donald Lamont, Hyperbaric & Tunnel Safety and Roy Slocombe, Director of Herrenknecht International to link with the joint BTS/ITA international seminar on high-pressure compressed air work.

19 APRIL 2012
Harding Memorial Lecture
Speaker to be confirmed.

24-26 APRIL 2012
Shaft Design & Construction Conference
See main listings.

11 MAY 2012
Annual Dinner
At The Brewery, Chiswell Street, London

17 MAY 2012
Meeting to be confirmed

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. Fax: +44 20 7936 6826 Email: editor@tunnelsandtunnelling.com Web: www.tunnelsandtunnelling.com

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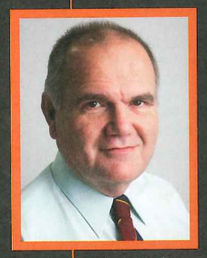

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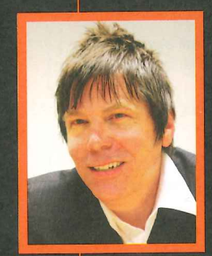

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Tunnels & Tunnelling International ISSN number 0041-414X is published monthly for US$226 a year by World Market Intelligence Ltd (www.worldmarketintelligence.com), a Progressive Media Group company, John Carpenter House, 7 Carmelite Street, London EC4Y 0BS, UK. Periodicals postage paid at Rahway, NJ.
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