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June 2017

Tunnels
AND TUNNELLING

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INTERNATIONAL EDITION
June 2017
Tunnels
AND TUNNELLING
BATTERSEA
BRANCH
Excavation begins on the
Northern Line Extension

NATIONAL INSTITUTION

Alex Conacher
The *Tunnels and Tunnelling* editor has been with the magazine since 2010

In the UK the Institution of Civil Engineers (ICE) has been running a tunnelling exhibition. It follows on the heels of an exhibition for bridges, which was rumoured to have attracted 15,000 visitors. The challenge given to the engineers of the British Tunnelling Society by the institution was to promote the event enough to beat this goal by the time the exhibit closes in November.

The ICE states: "ICE invites you to visit the hidden world of underground engineering. From the worms that inspired famous engineer Brunel to the mechanical giants burrowing under our modern cities, the art of tunnelling has come a long way. This latest free ICE exhibition takes you on a historical journey that shows you some of the longest, deepest and most advanced tunnels in the world. The exhibition runs for six months at ICE's Infrastructure Learning Hub at One Great George Street in central London."

Entry is free and the exhibition is open 10am-5pm Monday to Friday (except public holidays). You can find the ICE at One Great George Street, Westminster, London, SW1P 3AA. Just walk in and ask the receptionist to point you in the right direction. Groups of 10 or more need to book in advance, for this please contact debra.francis@ice.org.uk

Among the activities are:

- Virtual reality tunnel exploration
- Drive a tunnel boring machine simulator
- Feel the teeth from an actual boring machine
- Timeline that steps you through history
- Interactive displays and quizzes - what kind of engineer would you be?
- Build-your-own Lego challenge kits
- Lots of models, photos and fact sheets

The venerable institution – which turns 200 next year – is looking for ways to promote the civil engineering profession. A task it is suited for, as civil engineering was not really a recognised profession before its existence, with much of the professional engineering association related to military endeavour.

As far as tunnelling in the UK goes, the second series of the BBC's 15 Billion Pound Railway has just been released. The first series of the Crossrail documentary saw a surge of interest in the tunnelling industry from the general public. Perhaps the ICE will find its work done for it, at least as far as tunnelling is concerned.

This month I am interested in how tunnelling is being promoted to the public in other countries around the world, and what its perception is. So please drop me an email and let me know

Cover

The front cover shows the Northern Line Extension TBM being lifted into place by a Kone crane.

Next issue

In the next issue of *Tunnels and Tunnelling International* we have a report from the Crossrail C510 site and a British Tunnelling Society Young Members' meeting report covering the use of tunnelling during war, and the resulting UXO disposal issues.

This month...

20 YEARS AGO

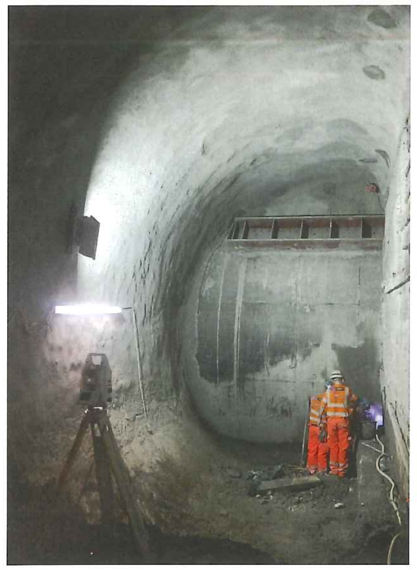
After two and a half years of tunnelling a JV of Kiewit Construction and Parsons Brinckerhoff has broken through on its 25ft diameter TBM drive for an underground nuclear storage laboratory at Yucca Mountain, Nevada. The five-mile-long loop drive for the US Department of Energy is a major feature of the laboratory, which is being constructed to investigate the area as a site for a high level nuclear waste fuel repository. The TBM used was a shielded hard rock machine made by Construction and Tunnelling Services and specially equipped to include a travelling gantry platform which could move independently of the TBM itself. This provided a base for geologists to map and sample the rock.

Tunnels and Tunnelling, June 1997, page 14

40 YEARS AGO

A contract for the supply of a tunnelling machine for a 3m diameter water tunnel in Oslo was won by Bouygues in March. The project is the 5km-long Oslo Sentrum Tunnel. The contractors are Astrup and Aubert. The tunnelling machine, to be manufactured at the Chambry, France, works of Bouygues will be built to the standard Bouygues design with a head consisting of three booms with single disc cutters. The total power will be 340hp of which 280hp will power the head. The head will rotate at between 12 and 40 rpm. The machine will weigh 30t.

Tunnels and Tunnelling, May/June 1977, page 25



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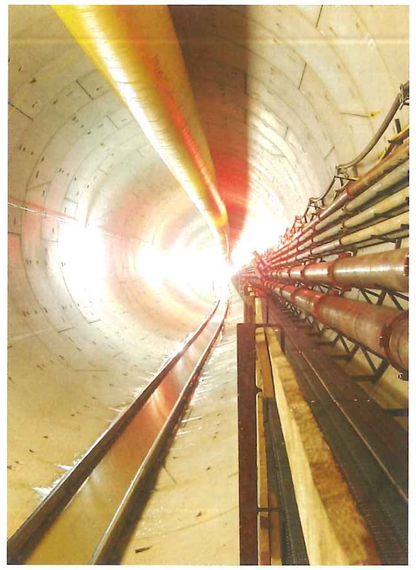

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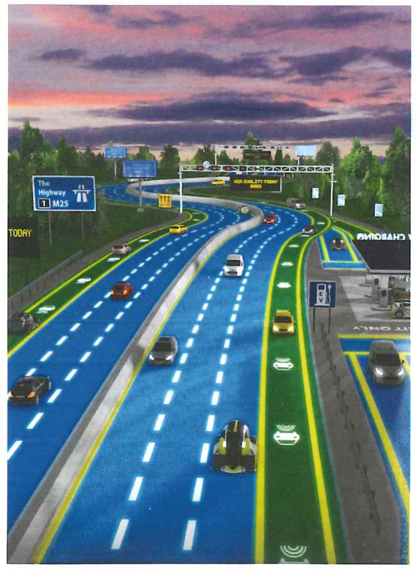

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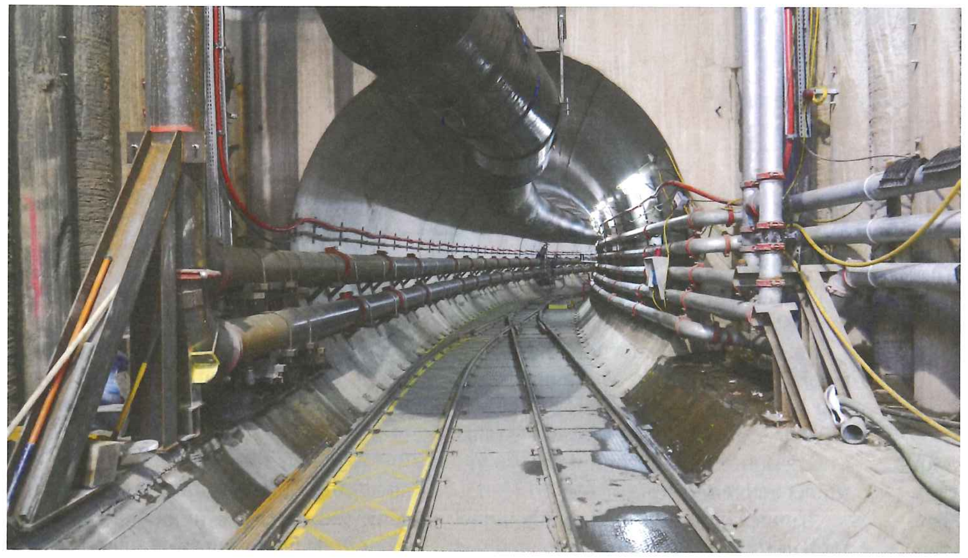
SHIELDHALL CONSTRUCTION HALFWAY COMPLETE

GREAT BRITAIN – Work on Glasgow's Shieldhall project is halfway complete, according to Scottish Water. In an announcement in early May, the client said that the milestone was reached as the TBM passed under Pollok Park. The project will be the longest wastewater tunnel in Scotland when complete.

The main portion of the works is a 5km-long, 4.7m-diameter segmentally lined tunnel designed by Aecom and built by the Costain-Vinci Construction Grands Projets joint venture. It is being excavated by a Herrenknecht slurry TBM that will erect around 3,250 rhomboidal rings during its drive, which are each 1.5m long, 250mm thick and reinforced with 35kg/m^3 of 4D Dramix fibres supplied by Bekaert Maccaferri. Tunnel Designers said that the 5D product was considered but they were satisfied with the strength of the 4D which resulted in a compressive strength of around 80N/mm^2, easily exceeding the specified 60N/mm^2.

The segments themselves are cast by FP McCann at its plant in Derbyshire in the English Midlands.

Geology along the relatively flat drive has consisted of clays, sandstone and mudstone. Teams have also had to grout extant coalmines of various sizes that date back centuries. JWH Ross provided an accurate mapping of these mines.



Top: A view of one of the bifurcation shafts that link the tunnel to the existing network
Above: Looking through the portal of the new Shieldhall tunnel

Tunnel cave-in at contamination site

US – The U.S. Department of Energy (DOE) Richland Operations Office declared an emergency at the Hanford Site at approximately 8:30 a.m. May 9 after a cave-in of a 20ft (6m) section of a tunnel used to store contaminated materials.

The tunnel is located next to the Plutonium Uranium Extraction Plant, also known as PUREX, which is located in the center of the Hanford Site, in an area known as the 200 East Area.

DOE reported no contamination has been detected following the cave-in. "Crews are continuing to survey the area for contamination. Crews worked through the night to construct a gravel road to provide a stable and clear path for workers to access the hole in the tunnel. Workers are currently filling the hole with approximately 50 truckloads of soil, which will be used to fill the hole."

In the 1950s and 1960s two tunnels were constructed next to a former chemical processing plant, PUREX. The tunnels were constructed of wood and concrete and covered with approximately 8ft of soil. The tunnels were constructed to hold rail cars that were loaded with contaminated equipment and moved into the tunnels during the Cold War.

During a routine surveillance of the area the morning of May 9, a 20ft-wide hole in the roof of one of the tunnels was observed, leading to the precautionary sheltering of employees and notifications to area counties and states. After no contamination was detected, the shelter in place order was lifted and employees were sent home from work early as a precaution. Workers continue to monitor the area for contamination as a crew prepares to fill the hole with clean soil.

Gomes joins SMEC

AUSTRALIA — SMEC has appointed Alexandre Gomes as chief technical principal Tunnels and Underground. Based in SMEC's Sydney office, the company said Gomes brings knowledge and global experience in the field of underground engineering to generate innovative, economical and practical engineering solutions.

Gomes has worked on major projects across Europe, Asia and the Americas providing his expertise across all stages of a project, from feasibility studies through to detailed design and construction supervision. His experience encompasses a broad range of ground conditions, ranging from very soft ground to hard rock conditions, and various construction methods.

Gomes's project experience includes: Metros in Santiago de Chile, Porto, London, Bangkok, Singapore and Taipei, Railway tunnels including the Taiwan High Speed Rail, Urban and non-urban road tunnels including the Concession Road Tunnel La Linea 2nd Tube (Colombia), AVO, Expressway Urban Tunnels (Chile), City Tunnels Porto and Schmitten Tunnel (Austria).

Large underground infrastructure projects for mining and numerous Hydropower projects in Chile and Latin-America.

Gomes has published more than 50 technical papers and articles and regularly provides high-level advice to contractors, consultants and clients on technical, forensic and contractual matters. He has been an Adjunct Professor for Tunnelling at the University of Chile and has been involved in worldwide training activities for engineering professionals. A member of the International Tunnelling and Underground Space Association (ITA-AITES), he is currently serving as a Vice President on the organisations' Executive Council.

FRA selects 2km B&P Tunnel replacement option

USA — The Federal Railroad Administration (FRA) announced its record of decision in late March on the preferred alternative to replace the Baltimore and Potomac (B&P) Tunnel.

The proposed project will replace the 1.4-mile-long (2.25km) rail tunnel located along the Northeast Corridor (NEC) in Baltimore, Maryland. Built in 1873, the B&P Tunnel is one of the oldest structures on the NEC, and is nearing the end of its useful life. The existing double-track tunnel was constructed out of brick and stone masonry, with additional materials added over time.

The selected alternative (3B) is estimated to cost USD 4.5bn, and would include 2 miles (3.21km) of underground construction through variable ground conditions including soils, mixed face and rock. The alignment would travel through an existing retaining wall adjacent to an LRT rail station to begin its descent below ground. The Selected Alternative would continue below ground in a gradual arc traversing below primarily residential city before exiting via a south portal located southeast of the existing NEC tracks.

The B&P Tunnel is owned by Amtrak and used for Regional and Acela intercity passenger trains, Maryland Area Rail Commuter passenger trains, and Norfolk Southern Railway freight trains. The Maryland Department of Transportation (MDOT) issued a Draft Environmental Impact Statement in December, 2015 that evaluated the environmental impacts of three build alternatives, and the FRA and MDOT issued a Final Environmental Impact Statement on November 25, 2016.

Sandvik and IBM to collaborate on productivity system

SWEDEN — A data-driven productivity and predictive maintenance system will be brought to the tunnelling industry by machinery manufacturer Sandvik and computing company IBM. Sandvik described the move as a collaboration that will bring advanced analytics to the mining and rock excavation Industry.

A Sandvik spokesperson added: "The growth in onboard instrumentation and data gathering capabilities in heavy equipment are presenting industries with opportunities to employ advanced analytics and models to identify and resolve productivity issues and improve process optimisation and performance.

"This combination of information services, remote data collection and data analysis will enable increased effectiveness by increasing productivity, saving cost and reducing time wastage. It helps mining and rock excavation companies make well-informed decisions regarding production plans and maintenance schedules and provides the opportunity to monitor and improve upon the general utilisation levels of their equipment."

"Sandvik has been working with mining customers on mine automation and remote monitoring of machines for more than 20 years. Our OptiMine and AutoMine solutions are also important systems for data collection and consolidation that provide us with a great platform to get a flying start with IBM analytics solutions."

ELON MUSK DISCUSSES TUNNELLING AT TED

INTERNATIONAL — Elon Musk, CEO of Tesla and SpaceX, called for a tenfold improvement in the cost per mile of tunnelling.

Musk shared his ideas for improving tunnelling at a TED Talk last month in Vancouver, while explaining his idea for a 3D network of tunnels that would carry cars on "skates" at speeds up to 200km per hour to mitigate traffic congestion.

When asked about the cost of building tunnels he responded "it's quite difficult to dig tunnels normally. I think we need to have at least a tenfold improvement in the cost per mile of tunnelling."

Musk said those reductions are possible "if you just do two things." The first he cited is cutting tunnel diameter by a factor of two or more. Second, he said, is to design a TBM to continuously tunnel and reinforce.

"Tunnelling machines currently tunnel for half the time, then they stop, and then the rest of the time is putting in reinforcements for the tunnel wall."

He added, "these machines are far from being at their power or thermal limits, so you can jack up the power to the machine substantially. I think you can get at least a factor of two, maybe a factor of four or five improvement on top of that.

"So I think there's a fairly straightforward series of steps to get somewhere in excess of an order of magnitude improvement in the cost per mile."

Musk started The Boring Company earlier this year.

TBM launches on Galerie des Janots

FRANCE – Contractor Eiffage Civil Engineering launched on March 3 the TBM mining the 2,750m-long tunnel for the Galerie des Janots water project in La Ciotat, France.

The refurbished Robbins machine has previously completed seven other successful projects across Europe and Hong Kong.

"It's a single machine 3.5m in diameter, 250 metric tons, and 135m long, that will work 24 hours a day for almost 10 months during this operation," said Marc Dhiersat, project director of Galerie des Janots for Eiffage.

The tunnel alignment passes under Le Parc National des Calanques, with cover between 15 and 180m, in order to replace the pipes that are currently being utilized for the water supply networks.

Robbins said currently, the machine is ramping up as back-up decks are being installed. As of April, the machine has bored more than 51m, mainly encountering limestone.

"Limestone is a rock easy to dig, but one can be confronted with the phenomenon of karst," explains Loïc Thévenot, director of underground works for Eiffage. "For this purpose, the tunnel boring machine is equipped with a probe drill. If the karst is small, we will fill it with concrete. If it is large, we will erect a small parallel gallery."

Galerie des Janots is one of the 14 operations designed to save water and protect resources, which are being carried out by the Aix-Marseille-Provence metropolis, water agency Rhône Mediterranean Corsica, and the State Government. The future Janots gallery will replace existing pipelines currently located in the railway tunnel that have significant safety and vulnerability deficiencies with estimated water losses of 500,000 cubic meters (132 million gallons) per year.

Harding Prize Winner 2017

GREAT BRITAIN – Omar Mohammed was awarded the 2017 Harding Prize. The Transport for London engineer was recognised for presenting the best paper, as chosen by BTS judges, at the May meeting of the society.

Mohammed's paper was on 'deep pile foundation Interceptions in tunnelling at Bank Station' and will be published, as well as a longer interview with the winner, in a subsequent issue of *Tunnels and Tunnelling International.*

The two runners up were Jennifer Henderson of TfL and Mohamed Fahed of Mott MacDonald. Henderson's paper was 'Getting on the right track: Early stage design in subsurface transport infrastructure' and Fahed's paper was 'Investigation into the splitting strength of SFRC segmental lining'.

The Harding Prize, which is named after the founding Chairman of the Society, Sir Harold Harding, is awarded annually or biannually to the winner of a competition to prepare and present a paper of interest to the tunnelling industry. The contest is open to all under the age of 33.

It was observed by several attendees on the night that the finalists faced more robust questioning than in past years and should be applauded.

Lee to manage tunnel projects for WSP Parsons Brinckerhoff

USA – WSP Parsons Brinckerhoff announced April 17 Sean Lee, a senior supervising engineer in the New York office, will manage tunnel projects.

In his new position, Lee is responsible for managing tunnelling and geotechnical projects. He has experience in numerical analysis, design and project management on major tunnelling projects in the US and abroad. Prior to joining WSP Parsons Brinckerhoff, he served as the Americas region tunnels skills leader at another engineering firm. A licensed professional engineer in Michigan, Lee received Ph.D. and M.S. degrees from the University of Illinois at Urbana, and a B.S. from Han-Yang University in Korea. He is a committee member of the American Society of Civil Engineers Metropolitan Section and a member of the Society for Mining, Metallurgy & Exploration.

LOWER THAMES CROSSING ROUTE ANNOUNCED

GREAT BRITAIN – Transport Secretary Chris Grayling announced the preferred route for the Lower Thames Crossing in April. The new crossing will create a new link between the A2 and the M25 orbital motorway and ease the burden on the busy Dartford Crossing.

The planned route will run from the M25 near North Ockendon, cross the A13 at Orsett before crossing under the Thames east of Tilbury and Gravesend. A new link road will then take traffic to the A2 near Shorne, close to where the route becomes the M2.

The bored tunnel was judged to be the least disruptive option.

Above: *The preferred route for the Lower Thames road tunnel*

THAI RIVER DIVERSION SCHEME ACCEPTS TBMS

THAILAND – April saw factory acceptance for the two 5.7m-diameter Terratec EPBMs that will bore the Bueng Nong Bon to Chao Phraya River Diversion Tunnel Project in Bangkok. These will be the newly-branded 'Terratec Tight Radius Shields' mentioned in a previous news article.

Located in the southeast of Bangkok, the 9,187m-long Bueng Nong Bon to Chao Phraya River Diversion Project is the third of four major flood prevention tunnels to be built under the Bangkok Metropolitan Administration's long-term plan to manage the severe flash floods that currently plague the Thai capital during the rainy season.

A number of tight curves necessitated an X-type articulation system, providing a maximum angle of 7.5 degrees to accommodate a curve radius of 35m.

A spokesman for the manufacturer elaborated on the drives: "The first machine to get going on the project will be the S54 machine, which will be launched into a 65m radius curve – from a 15m diameter shaft at the Bueng Nong Bon reservoir intake – southwards towards the Klong Nong Bon Inlet Station. Following an intermediate breakthrough at Klong Nong Bon, the TBM will then be turned 90 degrees within the 12m diameter shaft and re-launched westwards to the Klong Kled Inlet. The third and final run for the S54 machine will require a sharp 40m radius curve mid-drive to turn the TBM northwards to the Sukhumvit 101/1 Shaft, where the TBM will be dismantled. The total length of this first section is 5,523m.

"Meanwhile, the S55 machine will complete the two remaining sections of the tunnel. Launching from the 15m diameter Bang Aor Pump Station (Inlet) Shaft – which, along with the Bang Aor Pump Station (Outlet) Shaft, has been constructed within a large diaphragm wall groundwater cut-off structure – this TBM will also commence its 2,975m drive with a 65m radius curve, heading eastwards to the Sukhumvit 66/1 Inlet Shaft. Here, the machine will need to negotiate a challenging, double 40m radius, S-shaped spiral curve before completing its drive to the Sukhumvit 101/1 Shaft, where it will be dismantled and transported back to the Bang Aor Pump Station (Outlet) Shaft. Following reassembly, the S55 machine will complete a final 690m drive westwards from the Bang Aor Pump Station (Outlet) Shaft – again starting on a 65m radius curve – to the Chao Phraya River Outlet Shaft. Geological conditions along the alignment consist of soft to medium sandy clays, stiff clays and very dense sands, with an average overburden of 30m and a maximum groundwater head of about 1.5 bar."

The TBMs' soft ground cutterheads feature an open spoke design with the addition of knife bits to assist break-in and breakout of the shafts.

Traditionally reinforced 1.2m thick, 5m internal diameter, precast concrete segments will typically be installed as the machines progress, with shorter steel segments utilised during the course of the sharp 40m radius curves.

Excavation is due to commence later this year. When complete, the tunnel will have a drainage capacity of 60 cubic metres per second, providing much needed flood relief to an area of approximately 85 square kilometres.

Below: The factory acceptance took place last month

British explosives standard out for consultation

GREAT BRITAIN – The Code of practice for the safe use of explosives in the construction industry (BS 5607) is currently out for consultation. The period began on 19 April and public comment ends on 20 June.

The committee responsible, B/513 – Construction equipment and plant and site safety, gives this briefing on the standard: "This British Standard gives recommendations for the safe storage, handling, transport and use of blasting explosives and accessories in construction and demolition operations.

"Section 1 covers general recommendations for handling and safety. Section 2 is concerned with safety in the use of explosives in special applications and situations such as tunnelling, demolition, excavation and underwater working."

The explosives standard is not applicable to the following:

a) Blasting on offshore oil and/or gas platforms or structures, or any associated works
b) Underground works carried out for the purpose of exploiting mineral reserves and extensions to voids left following ore extraction, which are governed by legislation;
c) Operations involving the use of cartridge-operated fixing tools, which are specified by BS EN 15895 and whose use is covered by BS 4078-1.

The document can be found on the British Standards Institute website.

The organisation was founded in 1901 and sets out documents to aid standardisation across many disciplines and industries that are adopted and followed internationally to improve working processes.

Aldea makes Toronto appointment

CANADA – Aldea Services announced May 12 the appointment of Angel Del Amo Moreno as senior tunnel engineer in its Toronto office. Angel brings nearly 15 years of engineering and tunnel design experience to his new position, having most recently served as the lead designer on the Istanbul Metro in Turkey.

"Angel's experience from his work on major projects around the world is an important addition to the Aldea Services team," said senior vice president Bob Goodfellow. "His exceptional knowledge of tunnel lining design and the modelling of tunnelling impact on adjacent structures will serve our clients very well. Given the varying tunnelling techniques and materials that are employed around the globe, Aldea's international team experience gives us a broader perspective and increased possible design options to bring to the table."

In addition to his recent work in Istanbul, Angel has extensive international experience in precast tunnel lining design, SEM design, metro projects with complex soils, gassy tunnels and sealing systems, and extensive experience with tunnels in seismic areas, including Los Angeles and Istanbul.

"I feel that being a part of this team is a big step for me," del Amo said.

"It's exciting to have this diversity of ideas and experience to bring to our projects.

"I know it makes for a better effort end result for our Clients and ultimately local taxpayers."

HYDRO TUNNELS COMMISSIONED IN REPUBLIC OF GEORGIA

GEORGIA – In April 2017 a ceremony was held to celebrate the commissioning of the Dariali Hydropower Project in the Republic of Georgia, announced TBM manufacturer Robbins.

Many attended the ceremony marking the first carbon-neutral hydropower project in the world, including Georgian prime minister, Giorgi Kvirikashvili. The power station, an independent power project (IPP) developed through Dariali Energy Ltd, was a joint venture involving three other firms: Georgian private companies Peri Ltd and Energy LLC, and state-owned Georgian Energy Development Fund (GEDF).

The Dariali HPP gathers water from the Tergi River and directs it through the headrace tunnel to the power house located near the Russian–Georgian border. Each year, the site will generate 500 GWhs of carbon-neutral energy, with 70 percent of power production occurring during the country's summer months.

Robbins also invested in the project by gaining equity through supplying tunnelling equipment and services in consortium with contractor Peri. "Robbins understood the risk in the tunnelling portion of the project and we were compensated for taking on part of the risk. Peri is a long-time customer, as we supplied a TBM to them 15 years ago for a small project in Georgia. It was great to be invited to invest and risk share on this project, and to work together again," said Robbins president Lok Home.

The 5km-long headrace tunnel for the power station was bored with the use of a 5.5m-diameter Robbins Main Beam TBM starting in February 2012.

Due to the remote and mountainous location of the jobsite 160km from the capital Tbilisi, the machine was shipped in pieces to contractor Peri's workshop, where they were refurbished under Robbins supervision and then delivered to the site to be assembled. Each piece was transported by truck down narrow, winding roads that eventually gave way to dirt paths. Assembly at the jobsite was difficult, as the project site at a 1,700m altitude was blanketed in snow and components arrived in December. Bone-chilling temperatures often reached negative 15 degrees Celsius, and 40 below with the wind chill factor. Once the machine had launched, it encountered difficult ground including slate, sandstone, limestone and malms with fault zones.

"The main challenges we faced were boring the tunnel at a 6 per cent incline and having restricted access to service the machine. There were also two major landslides that delayed the project for over a year," said Home.

After the first landslide, the access tunnel, which had allowed mud and water to enter the power station, had to be relocated at a higher elevation and facing away from the river valley. When the machine was nearing the end of its bore, a second landslide blocked the exit portal for the machine as well as access to the main highway. Despite these challenges, tunnelling crews persevered and the machine successfully holed through in October 2014.

Throughout the construction process, careful steps were taken to minimize the carbon footprint. Although the plant's energy production is carbon emission free, construction of the plant was not. To offset these emissions, 7,000 seedlings are being planted all around the area in a reforestation effort. In years to come, the trees will absorb enough carbon dioxide to compensate for the emissions produced during the construction of the hydropower plant.

Overall, said Home, there is much to celebrate as the project has immense benefits: "Not only does it provide affordable electrical power for the country with essentially no pollution effects, but it also provided jobs during construction and will continue providing jobs during its operation and maintenance."

Left: The Dariali Hydropower Project was commissioned in April 2017

BERGEN 2017

The tunnelling industry gathers in Bergen for WTC 2017, the second time since 2010 a Scandinavian country has earned the event

HIGH MOUNTAINS, LONG FJORDS and steep valleys. A demanding landscape and tough climate with abundant precipitation meaning infrastructure construction in Norway is a severe challenge. This became all the more clear as road and rail started to replace the sea links that were the most important connections in the previous centuries. Yet the landscape also holds great opportunity. Many hydroelectric projects in the second half of the 20th century formed the industrialised Norway. Nature and culture combined to inspire innovative industry. The challenges of the topography have inspired Norwegian tunnelling engineers to become pioneers in management of projects that demand carefully tailored solutions.

Norwegian tunnelling engineers have continuously looked for new methods, improved working procedures, new machinery and equipment and learned from colleagues within both the national and the international tunnelling community. Short command lines, decision making on site and an adventurous spirit have resulted in new methods and ground-breaking projects, at the time they were built. Road and rail tunnels link Norway together.

The construction sector is among Norway's largest industries and looks forward to welcoming you to Bergen this June

Conference themes

SURFACE CHALLENGES – UNDERGROUND SOLUTIONS

Rapid population growth, increased urbanization and expected climate change will require major infrastructure investments, and wide use of underground solutions.

Urbanisation encourage underground solutions

Today more than half of the world's population lives in cities. The surface urban space available is limited. This means that infrastructure must be planned underground. Accordingly, the use of the underground needs to be carefully and coherently engineered with sustainability in mind.

New infrastructure must take into account, that future tunnels and underground facilities must be used to protect critical infrastructure from the forces of nature and human interference. Installations for oil and gas, information technology and communications, and civil defence are therefore increasingly being located in rock caverns. This ensures their operability even when disaster strikes.

More renewables necessary

Mitigation may be important, but climate solutions are even more so. Norway is today a major supplier in the renewable energy network thanks to the high number of hydro electric power plants. The demand for more green energy is sought-after all over the world and Norway has this expertise.

"Surface challenges – Underground solutions" is more than a slogan; for ITA-AITES and its members it is a challenge and commitment to contribute to sustainable development. The challenges are numerous and the availability of space for necessary infrastructure ends up being the key to good solutions. The underground is at present only marginally utilized. The potential for extended and improved utilization is enormous.

WTC 2017 Session topics

- Site investigation, ground characterisation
- Urban tunnelling (planning, design and construction)
- Strategic use of underground space for resilient city growth
- Utilisation of underground for hydropower projects (unlined tunnels and shafts, underwater piercing, air cushion chambers)
- Mechanised excavation (hard rock, soft rock and soil)
- Innovations in drill and blast excavation
- Large caverns (planning, design and construction)
- Underwater tunnels (strait crossings for road and railway, utility tunnels)
- Tunnelling for mining purposes
- Underground waste storage and disposal
- Innovations in rock support and water proofing technology
- Operation and maintenance
- Safety management of complex underground excavations
- Stability assessment, risk analysis and risk management
- Seismic design of tunnels and underground excavations
- Case histories – lessons learnt

Venue and dates

The Grieg hall
Edvard Griegs plass 1
5015 Bergen
Norway

9-15 June 2017

UPGRADING BOND STREET

London Underground Bond Street Station Upgrade Project (BSSU) is due for completion and open to public in April. In December's British Tunnelling Society Meeting, the project was told from the perspective of the SCL designer and the contractor working in a one team environment. Through innovation and utilising the latest technology they pushed the SCL design boundaries and developed a safe system of work by minimising the impact on infrastructure while optimising the excavation times to create necessary additional underground space. The speakers were **Richard Watts**, project manager, London Underground; **Steve Nuttall**, project director, Color; **Andreas Spiegl**, principal tunnel engineer, Dr Sauer & Partners and senior SCL engineer on site

Above: ***Bond Street is a London Underground Station and future Crossrail Station***

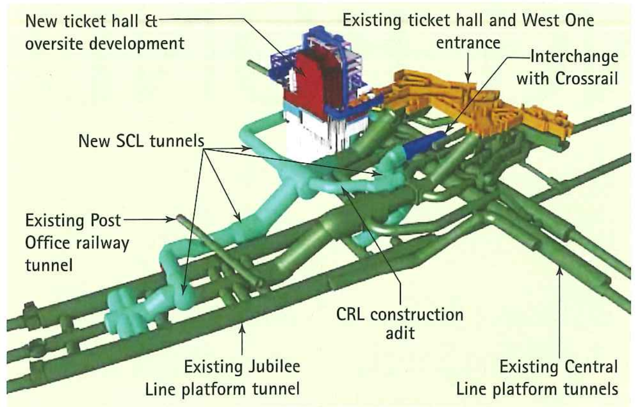
Anita Wu
Anita is an associate at London Bridge Associates and a BTS committee member

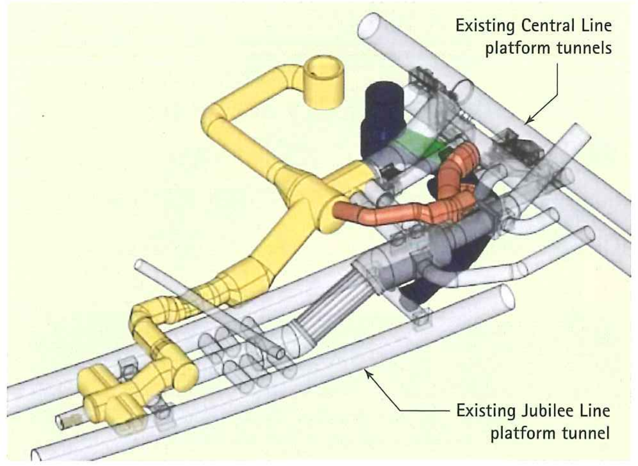
LONDON UNDERGROUND BOND STREET Station is located in the heart of London, on the west end of Oxford Street. The station was first opened in the 1900s for the Central Line followed by the Jubilee Line, which wasn't constructed until the 1970s, 13m deeper than the existing Central Line.

Bond Street Station suffers from severe congestion and currently serves 155,000 passengers per day. This is predicted to rise by 30 per cent by 2018 once Bond Street Crossrail Station opens. The main aim of the project is to provide congestion relieve and provide step free access. The major work for the project started in 2011 and is due to complete in early 2017.

Atkins was instrumental in the development of the concept design having developed the RIBA C design for London Underground in 2007. This design underpins the inclusion of the Bond Street works in the Crossrail Act and among other things settled on the election for Sprayed Concrete Lining for the majority of works carried out in BSSU.

Atkins was supported by Dr Sauer & Partners (DSP) as SCL specialist sub-





consultant and subsequently delivered the RIBA D pre-final-design to London Underground in 2008/09. Among other things, these works demonstrated the feasibility of some of the more challenging tunnelling works, which include tunnelling under the Central Line's platform and sensitive escalators.

When Costain Laing O'Rourke (Color) won the NEC Option C Contract Design & Build, they selected Halcrow and Atkins Joint Venture (HAT JV) as designer with DSP as SCL specialist sub-consultant and this joint venture drew on Atkins' knowledge of the Bond Street works together with Halcrow and DSP's delivery of the Tottenham Court Road Station

Top: ***Figure 1, New and existing tunnels at Bond Street***

Above: ***Figure 2, the Southern Tunnels***

Below: ***Construction in June 2015***

upgrade design. The HAT JV delivered a fully integrated multi discipline design that included tunnelling ground improvement, ground movement assessment, structure engineering, architecture, mechanical and electrical and fire engineering.

In addition to the SCL works, the temporary works and square works designers are Alan Auld Group and Donaldson Associates.

DESCRIPTION OF PROJECT

Prior to the construction of the two shafts, two new basement levels were constructed including opening of the shafts. A six-storey frame for the over site development building was built to provide working space for the project. The top three floors provided an engineers' office, workshops and welfare facilities, which are above two 17.5 tonne gantry cranes in the first three storeys.

In Figure 1, the dark green shows existing structures, which are the Central Line, Jubilee Line and an existing Post Office Tunnel. The orange shows the existing ticket hall.

BSSU will provide congestion relieve by providing a new entrance to the station, a new satellite ticket hall, additional escalators, lifts and passageways. The project will also improve fire safety in the station and a connection to the Bond Street Crossrail Station.

The tunnelling work was split into three areas, Northern Tunnels, Southern Tunnels and Crossrail Link Passage.

Northern Tunnels refers to the northern end of the Jubilee Line, which includes a new inclined escalator barrel, crossing under the post office tunnel, the Jubilee Line Overbridge and the new binocular tunnels.

Southern tunnels refers to the Central Line and the southern end of the Jubilee Line, which consist of low level passage, a new lift shaft and a new stairway to the Jubilee Line (Figure 2).

The new Crossrail Link Passage refers to a series of connecting tunnels linking the Southern Tunnels to the existing station passageway and Crossrail station, which is currently in construction in the south of Oxford Street.

GEOLOGY

The geology at Bond Street station is a typical London geology. A majority of the tunnels is in London Clay with the deepest part a SCL tunnel 30m below street level in Upper Mottled Clay of Lambeth Group.

KEY CHALLENGES

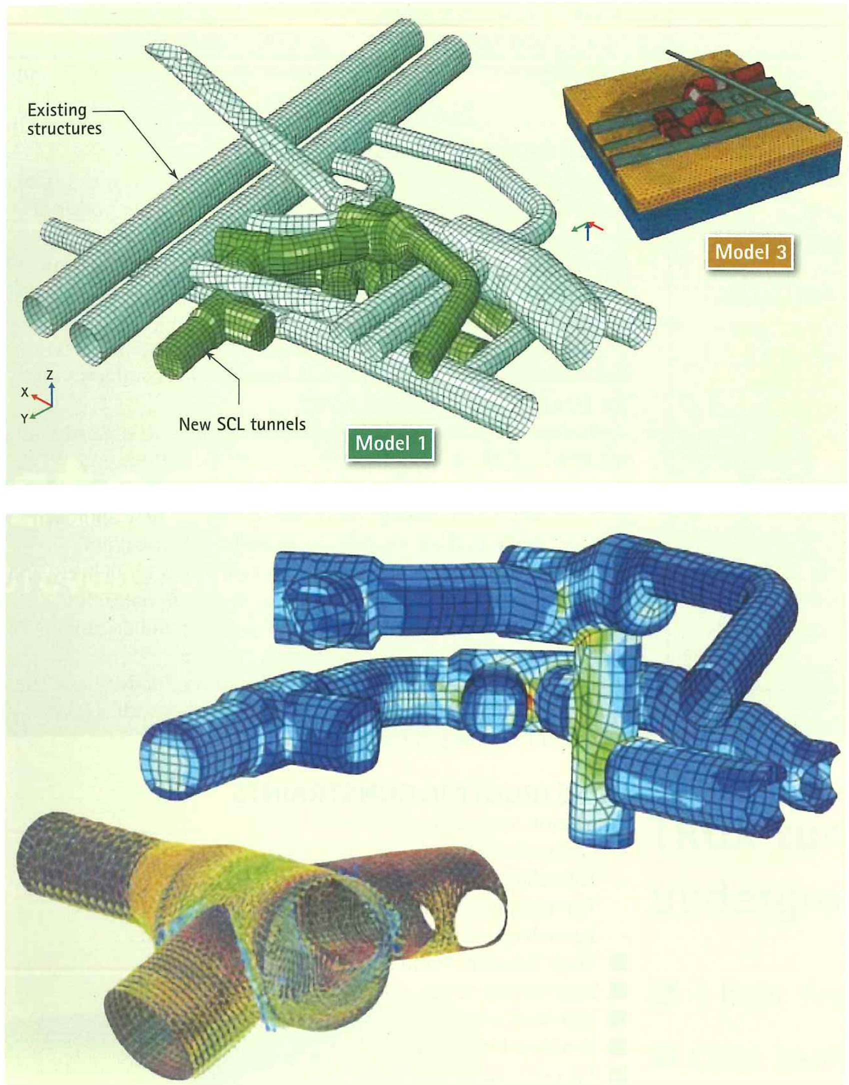
There are many challenges on BSSU. The project includes approximately 400m of very complex tunnel geometry and alignment due to the limit of deviation and existing structures. There are approximately 25 different cross sections with transitions between each of the cross sections. The longest straight part of the tunnels was 4/209 and the pilot tunnel for Connection Chamber 1, which was 45m long. During the construction of these tunnels, both underground lines have remained operational.

There were two tight corners that were a challenge to construct. There was also potential to find sand channels in the lower part of the tunnels.

Due to the existing building foundations, there was only 4m distance between the crown of the tunnel and the bottom of the foundation pile.

Compensation grouting was implemented for ground settlement mitigation. Compensation grouting pipes were installed to be able to react if more settlement than expected was to occur.

All tunnel works were carried out on a limited site in the footprint of a demolished bank building on Oxford Street. The site includes three silos, two access shafts and other equipment.



DESIGN

The monitoring system for the project was installed in 2010. The design of the SCL also started in 2010 with the review from the outline design of the tender document. The design team carried out value engineering and came up with safety improvements and then focused on critical design issues.

After this stage, the design team carried out the conceptual design, which included the initial sequencing assumptions, lining thickness calculation, 2D Finite Element Analysis and internal space-proofing validation.

This was then followed by detailed design that included 3D Finite Element Analysis and 3D CAD modelling, staged constructability co-ordination, coordination with the compensation grouting designer, primary lining and secondary lining steel fibre reinforced sprayed concrete and sprayed waterproofing membrane.

SCL DESIGN CONCEPT

The concept is that the primary lining has to support the short-term load and the secondary lining to support the long-term load, assuming that the primary lining will deteriorates in time. The secondary lining is fully tanked with a sprayed waterproofing membrane design. The design loads include full water pressure and ground load and additional surcharge load.

Top: ***Figure 3, the project used three different models***

Below: ***Tunnel construction in 2014***

The Finite Element specialist divided the project into three models to accommodate the large size of the station and optimise the performance of the analysis because it was such a big model (Figure 3).

Construction of tunnelling started in mid-2013 with shaft one excavation and SCL tunnelling started in January 2014.

The most important process during SCL construction is the Required Excavation and Support (RES) process, which includes RES meeting; review of tunnel ground conditions; tunnel, surface and surface structure monitoring; SCL material performance and agree plan for tunnel advance, for which a RES Sheet is issued with details of advance and support requirement. Shift managers carried out the RES briefing to shift engineers and workforce including miners, pitboss and occasionally to London Underground inspectors and SCL engineers.

The Jubilee Line Overbridge is a hybrid SCL and square work construction. The SCL top heading resting on the square work bench. The trains for the Jubilee Line were in operation during construction of the overbridge. During construction, it was decided to complete the secondary lining for the top heading with a cast in-situ lining.

The post office underpass was also a challenge because of the complex geometry and transition. It wasn't perpendicular so it was a challenge for the surveying team to input the setting out information correctly.

At the end of the Jubilee Line are the binocular tunnels. The construction sequence was chosen to minimise the deformation of the Jubilee Line tunnels. The right-hand side was excavated first followed by primary lining and secondary lining, then excavation of left-hand side followed by breakout of the side wall.

The interesting part was to the connection of the waterproofing and secondary lining. The complex sequencing was also a challenge for the team.

Questions from the floor

Kevin McManus: Was the design advantage gained by that worth perhaps some of the disruption to the production cycles that were occasioned by the need transition at very short frequency. If a more uniform cross section more applicable, would you be other options for lining that uniform section?

AS: There would be definitely other options and maybe more efficient to have more uniform cross section and maybe run through with the biggest one, but the contractor was involved from the design stage and have asked for the cross sections to be as small as possible. According to this, it was designed. This is also a very good lesson learnt. It would have been better to have more uniform cross section and maybe change the lining thickness if necessary. However, the tunnels were very close to adjacent structures, and if the tunnels were bigger then there may be more deformation.

Richard Foord: Could you please explain the choice of waterproofing system and the composite lining offered and explain how that came to be?

SN: It seems that the sprayed lining was a suitable product to use. The initial thought was that the lining of thickness can be achieved in one spray, but a number of things needed to be considered. We got to understand it better with the training and help and support from BASF.

The construction of the Lift 3 shaft was redesigned to improve construction sequence. The original design was to build Lift 3 Shaft from Connection Chamber 2 to connect to 6/210. This didn't work for the programme and the construction sequence was redesign by one of CoLOR's engineer to start construction of part of Lift 3 shaft from the Southern tunnels and then finished the shaft after completion of the construction of Connection Chamber 2.

Another redesign is on top of Lift 2 shaft. The original square work design was changed to a SCL design between two live Central Line tunnels. There was very limited space with access issue. Monitoring for all existing cast iron segment of the platform tunnel adjacent showed results well within the calculation and expected range.

Challenges relating to the ground conditions included one water bearing lens that was breached and created problems with water ingress in Lift 3 shaft. In the end, the team used a pocket excavation method, with immediate SCL application using sheet pile support, straw and sand bags to stop the water inflow.

Below: *SCL work in September 2014*

ONE TEAM APPROACH

TFL purchased one building for the BSSU site, which was a bank built in the 1960s. The building was bought with the power of the Crossrail Act. Demolition had to be carried out extremely carefully, as the building's neighbours included the Tanzanian High Commission. The Crossrail Act did not apply to the Tanzanian High Commissions.

The project worked collaboratively from the beginning. Responsibility for delivery and cost remains with contractor and the LU team to observe and accept.

As times went on, the commercial differences developed and the relationship between the contractor and client became strained. At a later stage in 2013, it was decided by senior management of the client and contractor that a new approach was required and the 'one team' was born. The one team approach allowed the construction team to focus on delivery and facilitated workshops for agreeing on completion dates. It promoted a more collaborative way of working and a combined team to jointly responsible for delivery.

This approach worked well especially for productivity and the information flow improved dramatically together with a joint approach for problems solving.

CONSTRUCTION CONSTRAINTS

Constraints included:

- Congestive site
- Tunnelling under the Central Line
- Tunnelling over the Jubilee Line
- Tunnelling with six Victorian sewers in the area:

■ Kings Scholars' Pond sewer
■ Westminster sewer
■ Mid-level sewer
■ Stratford Place Sewer
■ Tyburn sewer
■ Marylebone Lane sewer

As well as the sewers, there were also 24-inch and 36-inch water mains that were realigned. There were also gas main, fibre optics, and other LU assets.

A pedestrian is 36 times more likely to get knocked down by a car on Oxford Street so the project team, including miners, must only cross with the green man.

Other stakeholders included the Botswana High Commission, above the binocular tunnels as well as a private members club and a Kabbalah centre.

The project also introduced behavioural based safety technique.

Collaboration is a journey. To achieve the best safety culture, the best quality culture, it takes time and requires regular engagement, positive reinforcement, inclusion of all parties and most importantly regular checks that it is on the right path.

'What changed after the one team plan was launched?' was asked to the team members and the answers by the team were as follows:

■ Joint ownership
■ Improved efficiency
■ Increased familiarity and interaction
■ More trust
■ Clearer communications
■ Sharing of knowledge and experience
■ Improved working environment

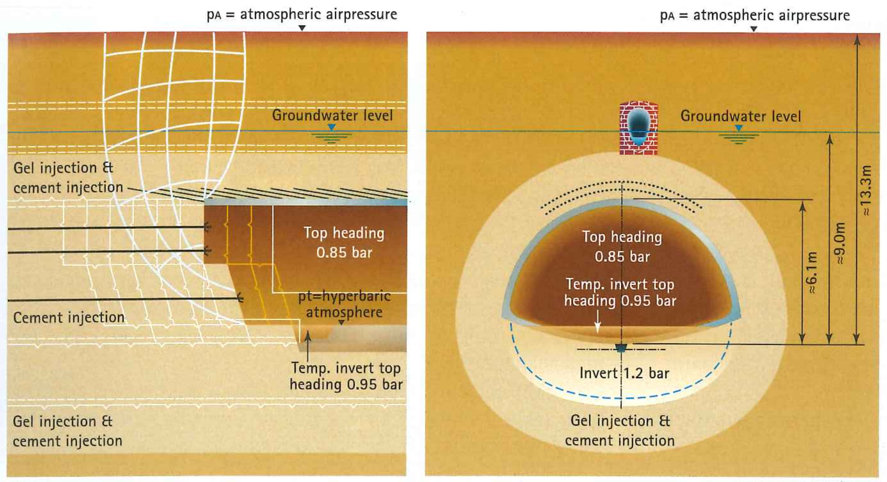
KARLSRUHE CUTS

Creating the first underground metro line for Karlsruhe in Germany has required a trilogy of tunnelling methods and extensive monitoring to protect the busy city

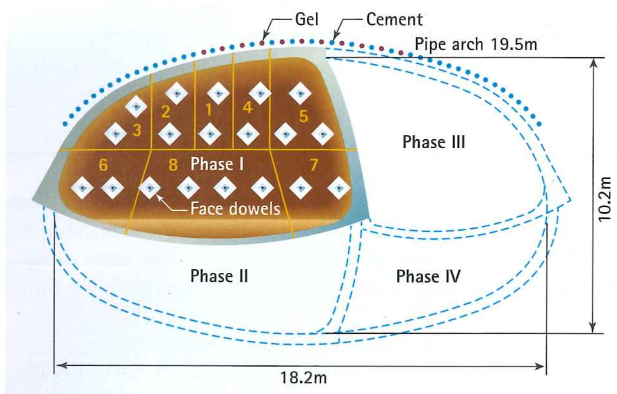
Above: Three types of excavation including TBM are being used for the project

CREATING THE FIRST UNDERGROUND train system in the German city of Karlsruhe is not straightforward. The high groundwater level, the sand and gravel strata, the shallow depth of tunnelling and the requirement to keep the existing metro running above, meant that one solution did not fit all on this particular scheme. "I think we are using almost all tunnelling technologies that exist in Karlsruhe," remarks Harald Burgstaller, project manager for the tunnelling contractor BeMo, under the EUR 295M (USD 331M) contract awarded to ARGE Stadtbahntunnel Karlsruhe. "We are building seven stations using the cut and cover method, the main tunnel is a hydroshield, and we are building a conventional tunnel under compressed air," he says.

Bernadette Ballantyne
Bernadette is an engineer and freelance technical journalist



Above: Extra support in an area of very low cover



Left: The project used NATM for part of the tunnel excavation

Left: An artist's station render

Below: The hydroshield site

Starting construction in October 2010 the project began with station construction at Europaplatz before bringing in the 9.3m diameter Herrenknecht Mixshield machine in July 2014. With groundwater at just 4m below ground level the machine was the most appropriate choice for supporting the tunnel face during construction. In this hydroshield model the excavation chamber is divided by a submerged wall which at the front is filled with a suspension to give better face support.

The rear section is filled with suspension to just above the machine axis and counter pressure from the face comes from a compressible air cushion in this upper area. As a result, the machine can withstand heterogeneous geologies and high water pressures of more than 15 bar.

The 90m-long machine was set up at the easternmost station Durlacher Tor and space was constrained. "We needed a huge set up. To mix the bentonite, to treat the wastewater, different storage areas--all this was on the surface of the station," says Burgstaller.

There was only space to store 30 of the steel reinforced tunnel lining segments at any one time making the logistics crucial and trucks carrying the segments from Glass Gmbh in southwest Germany arrived daily.

By November 2014 the machine was ready to begin its 2.05km bore placing the 2m-long segments in a 6+0 arrangement creating a final inner lining of 8.2m. Face support pressure varied between 0.5 and 1.1bar and thanks to the shallow depth risk of blowout was a key challenge. Running beneath the busy city centre of Karlsruhe the overburden ranged from just 4.9m at the east to 6.9m as it progressed westwards. "We are really shallow. We have extensive monitoring," says Burgstaller.

In charge of this extensive monitoring was BeMo chief of monitoring Ulf Tetzlaff. "We had levelling bowls on many houses, all houses we mounted prisms for automatic total station monitoring. We have points in the ground automatically monitored by total stations, we have special vehicles for the tracks," he explains, noting that the car would drive over the existing tramway every three hours during the TBM drive.

"Then we have a lot of extensometers at different cross sections all over the city to see if there is any deformation in the ground based on the tunnel excavation. We have a lot of inclinometer points in

Serving a growing city

The need to increase capacity for the busy trams serving Karlsruhe in Germany has been acknowledged for over 20 years. Not only do these commuter lines provide vital links through the city, they are also serviced by hybrid tram-trains which can travel from the regional Deutsche Bahn rail network directly into the city meaning that the growth has been far beyond that usually experienced by light rail systems. In 1997 123.6 million people used the system but by 2010 this had grown by an incredible 43 percent to 176.6 million.

The initial proposals for a new tunnel to serve regional rail - leaving the existing tram lines in the pedestrian area was rejected in the late 1990s and by the turn of the millennium a new proposal had gained support.

The existing tram lines running through the Kaiserstrasse area of the city centre would be placed underground leaving a rail-free pedestrianised city centre. At the same time a 1.6km road tunnel would be built to the south of this pedestrian area to divert some of the 10 lane highway, the busy Kriegsstrasse, below ground. This would free space for more light rail to run alongside the highway. This two pronged approach became known as the Kombilösung and a new client was formed to deliver it: the Karlsruhe Rail Infrastructure Company (KASIG).

The first part of this project, the Kaiserstrasse tunnel began work in October 2010 (see main article). This 2.4km rail tunnel also included a further 1.0km of south-north tunnelling to provide a connection line in to the central Marktplatz station (see map). The underground work is set for completion in May, after which time the fit-out works must commence. Public transport operator Verkehrbetriebe is currently designing the system which is yet to be tendered. This first section of the project is scheduled for opening in summer 2020 after a seven month testing period. Construction work on the second major tunnel, the Kriegsstrasse tunnel began this month (April). Determination of the final tram line network is also under consideration as is the strategy for station security.

For Verkehrbetriebe the construction period has been a challenging time, not least with the blow out that forced the tram traffic to close for 12 days. Every public transport company in Germany has to provide a Betriebsleiter who has personal responsibility for the operation of safe public transport. In Karlsruhe this person is supported by four deputies who have been closely supervising the construction works to ensure that the plans are being followed in terms of the temporary construction works underway and the final designs implemented. In turn Verkehrbetriebe is supervised by the Technische Aufsichtsbehörde für Strassenbahnen which gives the organisation permission to operate the system.

the ground also for the tunnel areas but even more around all the pits or sheet piled walls."

These inclinometers came from Germany's Gloetzl whereas the total station monitoring was supplied by Leica. All this data, including some manual monitoring information, was fed into an IRIS tunnel software package from VMT/ ITC Engineering. This then collated the information and sounded alarms if the movement hit certain trigger levels calculated using finite element modelling. Manual data entry came from areas such as building cellars adjacent to the tunnel. "We observed if there was any damage or differences to the day before," says Burgstaller. "The pre-calculated worst case scenario movement was 16cm. This would be catastrophic. But the maximum movement that we had was just 5mm along the axis of the tunnel. In reality we were much better than the calculation."

As a precaution the team undertook grout and gel stabilisation to support the buildings identified by client KASIG as being the most vulnerable. "We had five buildings which were really sensitive we did the grouting and on the rest just the monitoring. I would guess around 450m length of buildings, all next to the hydroshield, were protected in this way," says Burgstaller.

Although the tunnelling was completed on time by September 2015, achieving a maximum rate of 32m in one day, the bore did have some setbacks. An incident at the Lammstraße station held up tunnelling for three months. "The station is so small as we advanced the groundwater level increased and we had a change of geology, an old unexpected channel, so in total this was too much for the balance at the front of the shield and

Above: ***Segment mould with rebar awaiting pour***

Right: ***Crews celebrate breakthrough***

Above: ***The TBM breakthrough***

the face collapsed," says Burgstaller.

Fortunately, the concrete station roof had already been constructed protecting the buildings above so there were no adverse effects at the surface. To rescue the situation the team - after getting access under the concrete lap - had to, fill up the weld puddle, repair some pipes in the digging chamber and unblock cutting wheel.

Just when tunnelling was back on track a second incident caused another problem. "At the end of the station we had a diaphragm wall and on the outside of the station we had a high cement injection block as additional measure to ensure that when the machine comes from the station out to the normal ground, nothing happened. This block had a leak. So, we had a blow out," says Burgstaller.

Fortunately, the site team had noticed some ground movement on the road above and closed it to traffic just in the moment the blow out erupted. This time the delay was only two weeks. The work recommenced after the team unblocked the machine with a maximum pressure water jet, using the same method as before.

UNDER PRESSURE

Less eventful has been the compressed air tunnelling which is taking place along the north-south line running from the Marktplatz in the north where the lines meet, down to Ettlinger Tor station. Known as the Karl-Friedrich Strasse, this section consists of a 200m regular cross section but then widens over a 50m length. "Of course this is much slower advance. The distance is too short to use the hydroshield machine and the geometry of the tunnels is changing. We start with 80m² cross section and we end with 180m²," says Burgstaller.

Once again the low overburden presented the risk of blowout and the team also wanted to limit the potential for air loss so this section of tunnelling ground reinforcement was carried out around a 2m circumference with cement in the first phase and gel in the second. "We had a maximum loss of compressed air at 500m³/minute. But we expected just 140m³/minutes so we had to employ more compressors to commit the amount of compressed air that we needed. The ratio would have been much worse if we had not done this injection," says Burgstaller.

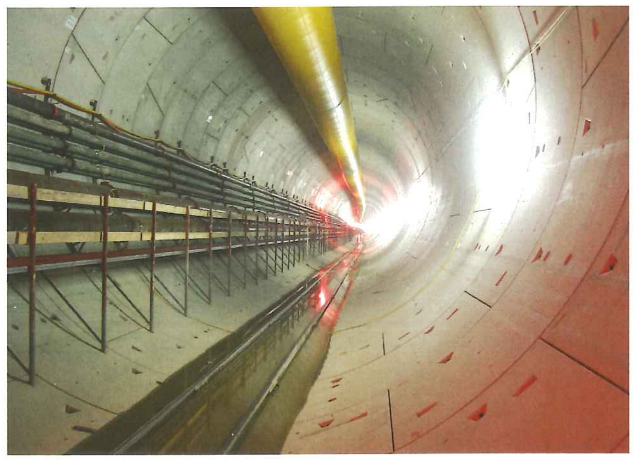
Using traditional NATM for the majority of the works the tunnel required a 300mm shotcrete lining reinforced with 50 to 60, 4m long, 32mm diameter spiles with 150mm spacings. A lattice girder is also placed every metre. For face support 10m long 12stk face bolts were inserted. The permanent lining to create the 8.2m diameter tunnel varied from 450mm to 1300mm of reinforced concrete lining using concrete of strength C30/37

At the enlarged section the tunnel runs beneath a historic sewer with an overburden of just 1m an alternative methodology was required to protect this piece of vital and historic infrastructure. "Under the sewer we did the pipe arch umbrella with steel pipes injected with gel and cement to stabilise the ground," explains Burgstaller. "And then because of the thick cross section we excavated in 4 main phases with 8 sections in each phase. Each phase took several weeks," he says (see diagram page 25).

Each phase meant excavating a section of around 40m in length. The primary lining included 400mm of reinforced shotcrete with face bolts. The final lining here is between 500mm and 2500mm reinforced C30/37 concrete. "In this section at the moment we have about 200 people because we are doing the advance of the invert and the inner lining," says Burgstaller. "We also have to consider that under compressed air we have reduced working time because of the heavy work."

With just 60m to go construction is almost complete on this section now. Looking back on this highly complex scheme Burgstaller says that the biggest challenges were not technical but about balancing the needs of all of the stakeholders affected by this inner city project. "There are many parties, organisations and companies that have interests here and to find solutions which are OK for everybody is the most challenging thing"

Right: ***The underground work is set for completion in May***



BRANCH TO BATTERSEA

Paola De Pascali met TFL senior project manager Mark Thompson and FLO engineering manager, Oliver Newman to talk about the Northern Line Extension project

Above: The extension project will construction north and southbound tunnels

Paola De Pascali
Paola joined the *Tunnels and Tunnelling* team in 2016 as a contributing editor

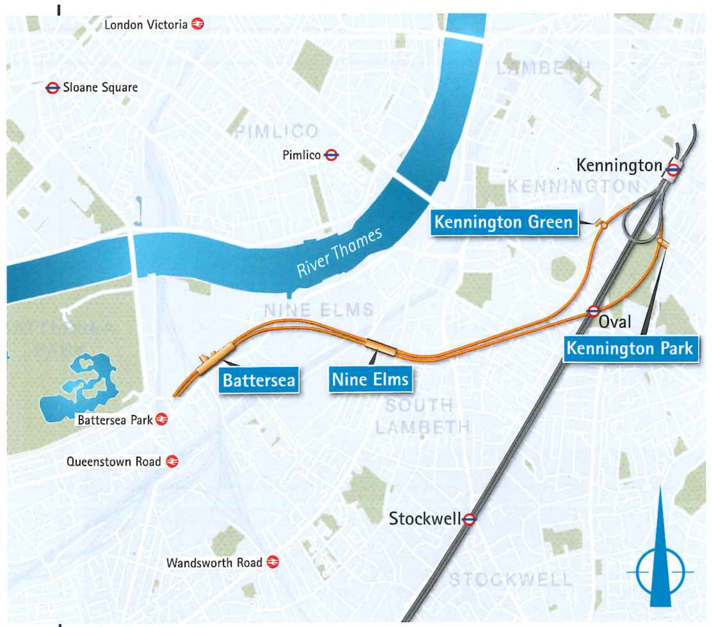
THE NORTHERN LINE EXTENSION (NLE) is an integral part of development to the Vauxhall, Nine Elms and Battersea areas of London. The project calls for new stations at Nine Elms, which will be the penultimate destination, and Battersea Power Station where the service will terminate. Two bored tunnels approximately 3.2km long will run from Battersea Power Station to the Kennington loop, connecting to the existing Charing Cross branch of the Northern Line via two newly constructed step plate junctions.

This solution will avoid a long-term closure of the Kennington loop, which would severely affect service on the existing Northern Line.

Cross passages at three locations along the tunnel alignment will form connections between the northbound and southbound tunnels to provide evacuation routes. Modifications to the existing Kennington Station will also be made, including four new cross passages to manage increased passenger flow.

The project is due to be completed by 2020 by main contractor Ferrovial Agroman Laing O'Rourke (FLO).

New northbound and southbound tunnels will be primarily excavated using two 6m-diameter EPBMs, launched in February. The 100m-long TBMs with an installed power of almost 2MW are capable of tunnelling up to 30m a day and have teams of around 50 people operating them. Six diesel locomotives manufactured for the project by Schoma in Germany, are equipped with the latest



low emission engines and will supply materials to the TBM as well as man-riding facilities for the workforce.

One full ring will consist of five full segments with arc length of 3,063mm and one key with arc length of 1,021mm. The alignment of the tunnel is achieved using specific configurations of rings. For example three consecutive left rings will provide a left curvature (and similar for right curve), however an alternating left and right ring configuration will provide a straight-ahead alignment. Segments will be bolted together using Grade 8.8 M24 bolts. The rings are designed for the project by Mott MacDonald and fabricated by Morgan Sindall in Kent.

Senior project manager, Mark Thompson says: "To assist the TBM we have a number of supporting systems. Material excavated at the face is removed via a screw conveyor onto a TBM belt, with two calibrated weighers; then onto the tunnel conveyor back towards the crossover box. It is then transferred to a

Top: ***Alignment of the Northern Line Extension***

Above: ***The Tube map showing the extension***

Bottom right: ***The launch shaft is near Battersea power station***

High Angle Conveyor, taken to the surface and deposited into the site muck bin. To facilitate rapid conveyor extension two conveyor loop towers are installed, which can feed additional lengths of belt as the tunnel progresses. The conveyors are all supplied by Joy and manufactured in Sunderland."

The spoil from the NLE is being transported to Goshems Farm in Essex by barges along the river Thames. The loading capacity at Battersea Power Station will take many thousands of lorry journeys off London's roads.

LAUNCH TUNNELS

In the Battersea crossover box two sprayed concrete lining (SCL) tunnels were constructed in order to house the TBMs and aid the launch process. These were 75m long and accommodated a shove frame at the face from which the TBM could launch. The tunnels were constructed from a top heading and invert and then later a full-face excavation. Advances of 1m at a time were achieved, excavating with a Schaeff tunnel excavator.

Works were controlled by a daily review meeting containing a representative from the client, contractor and designer. The shotcrete mix was designed for the NLE and supplied by Cemex from their Doveholes plant, with admixes and support from Normet in Coventry.

Once the TBM has completed its drive, it must be removed from the tunnel. In order to do this two 26m-deep secant piled shafts with a SCL formation in the pit bottom were constructed at Kennington Park and Kennington Green. Extensive de-watering was put in place at Kennington Park as the base of the shaft ran into the Lambeth measures beneath the London Clay with the potential of running water. Installed by WJ Dewatering, the 13 wells have successfully controlled water ingress along the shaft and the spray concrete lining tunnel alignment.

At the pit bottom a back shunt was constructed to allow the breakthrough of each TBM. In the opposite direction there is a spray concrete lining running tunnel (80m – Northbound; 280m - Southbound) constructed to connect the shaft to the existing Kennington Loop. Like the launch tunnels, 1m advances were completed by a tunnel excavator. A full-face excavation was adopted to remove the construction joint and to reduce noise and vibration beneath the residential area. The surveying system utilised the Amberg system for alignment and excavation controls.

"With the shafts being located in a residential area, combined with 24/7 working in the tunnels, acoustic buildings were constructed over both shafts in order to minimise disturbances to surrounding properties," Thompson says. Silent ventilation fans were installed within the buildings and a 50t overhead traversing

crane supplied by Kone was used for supplying materials and hoisting spoil. The SCL silos, pumps and the muck bin were all contained within the acoustic building, which was supplied and built by Dam structures in Yorkshire.

STEP PLATE JUNCTIONS

Thompson explains that the connection between the new bored tunnels and the existing Northern Line (Kennington loop) is being achieved by constructing junctions on each of the North and Southbound tunnels.

"The construction process included the excavation of a spray concrete lining pilot tunnel directly next to the existing tunnel, using SCL techniques," Thompson says. "From this opening, the existing cast iron tunnel was exposed on one side. An over dig then exposed the top of the cast iron tunnel, with megashore props and pre-tensioned steel cables being installed to minimise any defection and movement of the Northern line, which has remained in service throughout the works. Timber headings were then created underneath the existing cast iron tunnel. Once completed they were filled with concrete, utilising glass fibre reinforced cages to assist manual handling.

"This further secures the base of the existing tunnel and minimises settlement. The tight side of the existing cast iron tunnel was then excavated in stages using timber headings up to the overdig, all accessed from beneath, completing the excavation all around the existing tunnel."

The main structure of the new Step Plate Junction is then created using two sizes of Spheroidal Graphite Iron (SGI) segments, respectively 9.5m and 6.5m diameters. Supplied by DTS, these SGI segments will envelop the existing tunnel and will form the transition between two separate tunnels into one. The tunnel lining will be formed by precast concrete rings with internal and external diameters of 5.2m and 5.7m respectively. "Handling these segments is quite a challenge to get them in place, so we have specifically commissioned Tunnelling Engineering services to provide a segment erector to help manoeuvre segments into position on the TBM," says Oliver Newman, engineering manager at FLO. Newman says: "Whereas earlier step plate junctions had been formed entirely using traditional squareworks tunnelling techniques, we sought to maximise the use of sprayed concrete lining. This included excavating around the existing railway tunnel in a crescent shape. We have taken the SCL as far as possible, leaving squareworks in just the invert and 'tight side' of the existing tunnel."

"This major advance in mechanisation of the works is probably the aspect of the work we are most proud of."

Thompson explains that work on the Step plate junction is still on-going and they expect to complete it by July, and then will do cable diversions. After that, they will secure the necessary permissions in the autumn to connect the new and existing Northern line tunnels together. "We will do it in a series of 52 hours," Thompson says. "We have to do a short-term closure of the Kennington loop at Christmas to take out the old cast iron inverts and track bed and then create a new invert and install the new track turnout and connecting rails, thus connecting the NLE to the existing Northern line. "The plan is to minimise any impact on passengers because, over Christmas, London Underground can divert trains from the Bank branch to the Charing Cross branch," Newman adds.

TUNNEL CROSS PASSAGES

Over the 3.2km of tunnels there are three cross passages to provide emergency exit routes. "We have three cross-passages between the TBM tunnels, two are entirely in London Clay and another one is placed 50 per cent in the clay and 50 per cent in

Right: ***TBMs launched on the project in February***

the Lambeth Group, which is dewatered," Newman says. "However, we were very lucky with the geology because we will be tunnelling almost entirely in London Clay.

"These three cross passages will be excavated using a tracked excavator and constructed using a 200mm spray concrete primary lining. The connection between the tunnel cross passages and the TBM tunnels will be achieved by using spheroidal graphite iron (SGI) segments with four 1,200 x 1,600mm opening sets. Each SGI ring will contain 11 segments including 1 key and 2 removable opening panels. The segments are connected to each other using M24 bolts with hydrophilic grommets and gaskets. Once the cross passage is ready to be excavated the two opening sets will be removed revealing the open face.

"To relieve the increased customer flows resulting from the introduction of the NLE, four new cross passages will be

Below: ***The new tunnel diameter is 5.2m, and existing tunnel diameter is 3.8m***

constructed in Kennington Station," Thompson says. "They will be situated on the Kennington Station platforms and will connect the Bank and Charing Cross services on both the Northbound and Southbound platforms."

Each cross passage will be formed by SGI rings with an internal diameter of 4,400mm and will be excavated through timber headings. Each ring consists of 10 ordinary segments, two top segments and one key segment.

Top: Two TBMs are being used on the project

Above: Lowering the TBM

Below: Earth loaded onto the barge to travel to Essex

MONITORING

Extensive monitoring has been installed along the route, both in terms of monitoring ground movement in the extensive Georgian and Victoria properties around Kennington, but also along existing key assets including the current Northern Line tunnel, where shape arrays and frequent track and manual surveys have been used to monitor movement. The proactive review of monitoring led to a slight change in excavation sequence at Kennington Park to reduce loading on the existing cast iron tunnel and the lessons were then applied to the longer excavation at Kennington Green.

"As a project we have a wealth of ground movement and monitoring experience," Newman explains. "We have the automated monitoring to control in real time, displayed in our Settlement Valuation and Analysis Tool (sVAT) database, and that's a key aspect of the work. We can watch the rate movement and we can change methods as a result of that. We were fairly flexible in our design so we found the best solution to keep the job going.

"In terms of digital engineering we have a strong culture of using 3D models not just for the design but also to plan the works. For example, every time that we brief a method we use 3D images, which show the works in progress and bring the next stages of work to life. In this way we can think ahead and plan the next stage of the work."

ATMOSPHERE

"An example of the use of the 3D model was to give us much greater clarity on the conditions the team would face in the tunnels," Newman says. "Being able to identify where there would be dead-ends where the environment would likely be hot, humid and generally challenging meant we changed our temporary works sequence to greatly improve access and ventilation."

CONSTRUCTABILITY

Newman explains the reference design included five steps and rings. So the original lengths were 100m for the longer tunnel and 91m for the shorter tunnel. "But we ended up with a reduction to 60m for the longer and 53m for the shorter one," Newman says. "We knew minimising the workload was key to achieving our tight delivery programme so we worked the designers hard. Having overall control of the design made this possible, especially the track.

London Underground had generated 3D cloud surveys on the track and tunnels which FLO supplemented. We spent a long time looking at the exact positioning of our tie-ins to the existing track - only with the high resolution information did we have confidence to shorten our tunnels rather than assume a longer length to allow for uncertainty."

"The largest diameter of the junction had to accommodate the 3.8m diameter of the existing tunnel and the new tunnel which is generally 5.2m. We wanted to minimise this end of the tunnel to reduce ground movement so we focussed on efficient solutions for the emergency walkway and tunnel services. Fire, ventilation, architects and pretty much all of our disciplines were a big part of our tunnel design. Reducing the diameter by 1.1m allowed the overall cross section of the tunnel to be reduced by 20 per cent."

Thompson adds: "We also reduced five headwalls to three and removed gallery headings and compensation grouting. So we simplified the project in terms of level effort."

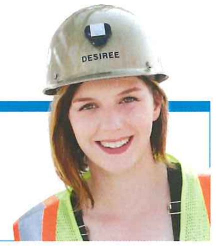
Regarding the impact on the surrounding areas of the NLE project, Newman explains they have a community liaison team to make sure residents are informed about what is going on. "We try to adapt to their needs and pursue changes that minimise impact," Newman says.

According to the government the NLE project will create up to 25,000 new jobs and 20,000 new homes, and it is essential to improve transport links to the area

THE MOST CHALLENGING

Turkey's Tough Geology puts TBMs to the Test. Robbins technical writer **Desiree Willis** reports

Desiree Willis
The Robbins technical writer has covered a range of topics for *Tunnels and Tunnelling*



Above: ***The Gerede Water Transmission Tunnel has been called the most challenging current tunnelling project in Turkey***

AT THE GEREDE WATER Transmission Tunnel in Central Turkey, a 31.6km-long water supply line has been designated a national priority due to severe and chronic droughts in the capital city Ankara. Drawing water from the Gerede River, it will be the longest water tunnel in Turkey once complete.

But completing the tunnel has been an obstacle in itself. The project has been called the most challenging tunnel currently under construction in Turkey, and with good reason. Out of three standard Double Shield TBMs originally supplied by a European manufacturer to bore the tunnel, two became irretrievably stuck following massive inflows of mud and debris. In 2016, a Robbins Crossover XRE machine was launched to excavate the final 9km of tunnel, but to do so it would need to cross dozens of fault zones and withstand intense water pressures up to 20 bars.

The Gerede Water Tunnel is just one tunnel at the top of a long list of challenging projects in Turkey, however. Like so much of what is considered difficult in tunnelling, the story of why Turkey's projects are so tough begins and ends with geology.

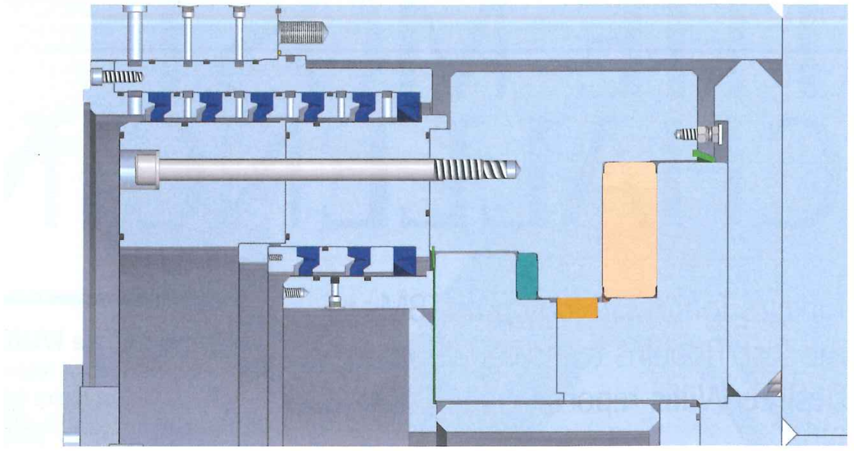
WHAT MAKES A PROJECT CHALLENGING?

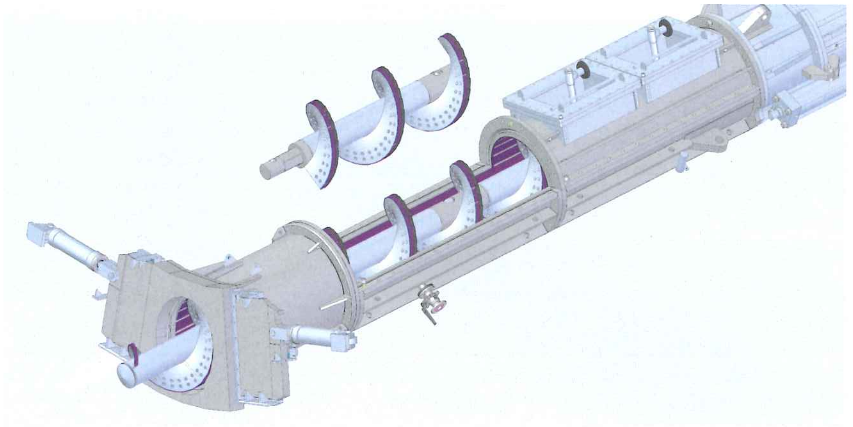
Turkey is in a tectonically active region controlled on a grand scale by the collision of the Arabian Plate and the Eurasian Plate. At a more detailed level, a large piece of continental crust almost the size of Turkey, called the Anatolian block, is being squeezed to the west. The block is bounded to the north by the North Anatolian Fault and to the south-east by the East Anatolian fault. Geology in the fault zones tends to be highly

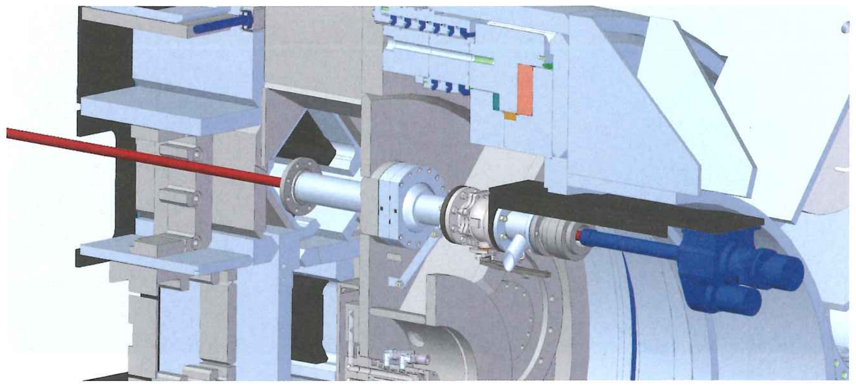
Right from top to bottom: ***Figure 1, The TBM was designed to statically hold up to 20 bar pressure using an extensive sealing system. Six outer seals and three inner seals (dark blue) protect the main bearing***

Figure 2, A specialised screw conveyor features replaceable wear plates along its length and can be sealed off and operated sequentially under high water pressure

Figure 3, Probe drilling is accomplished through twelve ports in the machine shield, each sealed by a ball valve



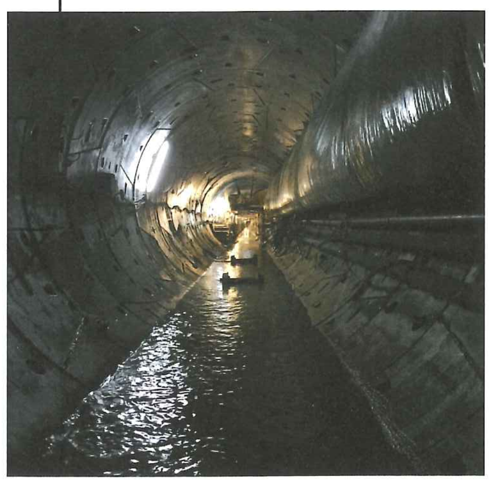




variable and unstable. Several current and recent projects are affected by these faults, including the Kargi HEPP, the Bahce-Nurdag High Speed Rail Tunnels, and the Gerede water tunnel.

At Gerede for example, geologic testing and borehole samples showed a mix of volcanic rock including tuff, basalt, and breccia, giving way to sedimentary formations like sandstone, shale, and limestone, all punctuated by fault zones that contained clay and alluvium. The ground conditions are of immense interest to Nuh Bilgin, professor of mine and tunnel mechanisation at Istanbul Technical University and Chairman of the Turkish Tunnelling Society. "I believe that [Gerede] is the most challenging project of all current tunnelling projects. I believe that after the completion of the project, it will have a special place in the tunnelling history of Turkey."

It's a very different geology from that of Istanbul, where many TBMs have been used for metro and sewer tunnels. "The geology in Istanbul necessitated the use of EPB TBMs in the area," explains Bilgin. Over the years it was discovered that EPB TBMs could outperform open-type and shielded rock machines as well as slurry TBMs in the city's mixed geology. That's not true in the rocky fault zones of Central Turkey. "I believe that in the North Anatolian Fault and East Anatolian fault zones or in high overburden, mountainous areas with high tectonic stresses, Crossover/Dual Mode type machines will have more chance to succeed."



Left: ***The Gerede Water Transmission Tunnel has been highly affected by the Anatolian Fault Zones that resulted in unstable and faulted geology***

Bilgin has had four decades of experience in geological research and tunnelling projects, and his decision is informed by field experiences. He also believes that a shielded rock machine with certain capabilities could get through the fault zones. "We had an experience in the North Anatolian fault zone at the Kargi HEPP where the squeezing of the TBM was a big problem. The TBM's emergency thrust system, shield lubrication facilities and multi-speed gearboxes played a big role in the success of the project. However, I believe that an experienced tunnelling crew, which is capable of understanding these necessities, is a key factor for the success of the tunnelling activities. In such cases I believe that the close cooperation between the machine manufacturer and the contractor will increase the effectiveness and the credibility of the project."

The 10m double shield machine was modified in the tunnel, effectively allowing it to operate like an EPB in fault zones, with high torque and low RPM. These are the same principles used in Crossover machine designs.

Also on the Kargi project, the machine utilised a canopy drill and umbrella arch to consolidate ground directly above and in front of the machine, and also operated with continuous probe drilling. "When probe drilling and umbrella arches are used together in a tunnelling project, machine utilisation time and mean daily advance rates may decrease considerably. However, the contractor must be aware of the fact that if these techniques are not used, the machine will most likely become jammed, necessitating a bypass tunnel that will require much more downtime," says Bilgin. As far as the selection of TBM type, Bilgin says there are several trade-offs. "A Crossover /Dual Mode type TBM may be a little more expensive than a classical single shield TBM, but this type of TBM may overcome many difficulties arising from the complex geology."

Above: ***Water ingress at TBM-1 combined with squeezing ground caused delays, but did not stop the machine from completing the tunnel***

REEXAMINING GEREDE

At Gerede, the Anatolian Fault Zone has certainly presented many obstacles. During the original excavation, the joint venture of Kolin and Limak purchased three 5.56m diameter double shield TBMs from a European manufacturer to deal with the challenging geology. Each machine was to bore a roughly 10km section of tunnel. The TBMs arrived at the site in 2011—the first machine (TBM-1) was launched from the north portal in a relatively homogenous section of rock with low cover of 13m. The TBM completed its 9,588m of tunnel while achieving good average advance rates. The machine encountered some ground water inflows and squeezing that caused delays but it was still able to complete its tunnel.

TBM-2 was launched from an intermediate shaft under higher cover, starting at 60m and reaching over 400m as it bored toward the south. The rock was more transitional in this section, and the TBM had bored a significant section of its 10,339m tunnel when it encountered a massive inrush of water that flooded the TBM and tunnel.

The TBM was boring downhill and the water had to be pumped out, which took some time. The TBM was deemed a loss, and removed from the tunnel.

TBM-3 began boring from the south portal under increasingly high cover that would reach a maximum of more than 500m. The TBM was several kilometres into its 11,653m downhill drive, struggling in karstic aquifer conditions that required polyurethane injection and slowed tunnelling, when its problem became worse. A high water inrush of 1,500 litres/second flowed into the tunnel, causing the machine to become stuck. This inflow resulted in enough pressure to crush the TBM shields and send cylinders catapulting into the back-up. Dye tests showed that the water had come from a river flowing overhead and entered into the tunnel through a cave system. As quickly as it had started, the Gerede Water Transmission Tunnel ground to a halt with two TBMs stuck 9km apart.

Left: ***Components of the Crossover XRE machine were transported into the tunnel for Onsite First Time Assembly (OFTA)***

A new strategy

The Kolin/Limak JV had to develop a new strategy given the incredibly difficult ground conditions. They contacted The Robbins Company, which suggested a Crossover (dual-mode type) TBM for the remaining 9km section of tunnel. The 5.56m diameter XRE (standing for a Crossover between Rock and EPB) could effectively bore conditions in both rock and mixed ground under water pressure by converting between modes.

The revised geology was now understood to contain more significant fault zones and an aquifer system that could cause high-pressure water inrushes of up to 20 bar.

However the ground was expected to improve as the TBM advanced and consist mostly of sandstone, limestone and tuff with a maximum UCS in the range of 100MPa.

Kolin/Limak needed a machine that could effectively bore in those wide-ranging conditions, but also statically hold water pressure up to 20 bar in the event of an emergency flow—a failsafe with which none of the standard double shield TBMs were equipped.

Cutterhead design

Due to the geology, the Gerede machine required a convertible cutterhead optimised for hard rock. Multiple abrasion-resistant deflector plates were included to handle abrasive rock chips as they entered the cutterhead chamber and into a screw conveyor. The cutterhead was designed for ease of conversion between hard rock and EPB modes, and cutter housings can be fitted with either disc cutters or tungsten carbide tooling.

In addition, the cutterhead is designed to operate in a single direction. The setup, which is used on all XRE machines, allows for greater efficiency while excavating, with lower power requirements and less chance of regrind. The problem of regrind occurs in bidirectional heads when already-excavated muck enters through the cutterhead and back out of the next opening, wearing the back portion of the cutterhead. The phenomenon can be very severe in bi-directional cutterheads depending on the ground conditions.

Drive system

To cope with difficult ground, the Gerede machine was also equipped with special gearing, allowing the machine to function as either an EPB or a hard rock TBM. This function is done by adding another gear reduction – heavy duty pinions and bull gears accommodate high torque at low speed, allowing the machine to bore through fault zones and soft ground without becoming stuck. By shifting gears the machine is able to output high speed in order to cut hard rock using the same installed horsepower.

High-water design

The new TBM was designed to statically hold up to 20 bar pressure in the event of a massive water inflow. In order to protect the machine from such high water pressure, an extensive sealing system was put into place. Around the main bearing, there is an outer row of six seals and an inner row of three seals. Between each seal, the cavity is filled with grease to ensure a constant pressure. In the event that the machine is shut down and an inrush of water overtakes the machine, a pressure sensor will detect this presence of water and flush the seal system with grease in order to continually protect the seals. The articulation joint and also the gripper and stabiliser shoes are sealed off in the same manner. All of these locations have two rows of seals with a grease-filled cavity between to hold constant pressure.

Specialised screw conveyor

Perhaps one of the most important parts of the Gerede TBM design is the screw conveyor. Because of the potential for massive amounts of water, the machine must have a sealed screw conveyor. However, running rock through a screw conveyor can be highly abrasive. In order to account for potential wear, the screw has been designed with replaceable wear plates along its entire length. The screw itself is also made up of short sections that can be removed and replaced if needed. Multiple access hatches are included for maintenance of the wear plates, while two large, removable outer casings can accommodate the change-out of entire screw sections.

A special feature of the conveyor is the ability to seal itself off so the TBM can continue boring. If a fault zone is encountered with large amounts of water, the machine will still be able to continue excavation. In this case, the screw can be used in a sequential operation. The rear screw conveyor gate is closed, sealing off the interior of the machine from the incoming water. The screw extension cylinders will then push the rear of the screw back, thus pulling the screw out of the cutting chamber and into the screw casing. Next, the bulkhead gates will close. The rear gates can be reopened and the screw conveyor can run, emptying the casings of water and muck. Once the screw has been emptied, the rear gate can be sealed. The bulkhead gates can then be reopened and the screw re-extended into the cutting chamber. Boring can then commence until the screw conveyor is once again full. Once the screw is refilled, it can again be retracted and sealed, starting the process over again. This process can be slow, but will get the machine through a fault zone and into better ground.

Above: Two double shield TBMs became irretrievable stuck or damaged amid massive mud and water inflows

Probe drilling

Due to the unpredictable ground conditions, it is necessary to detect and grout off zones of concern wherever possible in order to protect the machine from loose ground and water pressure. The machine utilises a standard array of 12 Ø100mm ports angled at 7° that are equally spaced around the rear shield. Each port is sealed by a ball valve until it is needed for probing. Ten of the same-sized ports are also located straight through the forward shield for probing and grouting. Six additional hatches are built into the pedestal at the front of the machine. The hatches can be used with a pneumatic percussive drill in the centre section of the cutterhead.

The probe drill on the Gerede machine also has an extra feature for cases of emergency. The drill is designed to pull

Below: The Robbins Crossover machine was assembled several kilometres inside the tunnel in an underground launch chamber

Left: The Robbins machine was launched to bore the final 9km of tunnel in summer 2016

back behind the tail shield and at an angle of 16°, so it can drill behind the shields and into the segment lining. If water has filled the cutting chamber and the pressure is high, drilling a hole in the roof of the tunnel will allow the water to spill out, thus relieving the buildup of pressure on the machine.

THE BORE PATH

The Robbins XRE TBM was launched in summer 2016. The machine is using some components from the original double shield TBM back-up, as well as the remaining segments being stored for the project. Crews excavated a bypass tunnel to one side of the stuck double shield (TBM-3), and the Robbins TBM components were walked in through the south portal. The machine was assembled using Onsite First Time Assembly in an underground launch chamber.

"The logistics of getting components through the existing tunnel were the most challenging thing. The assembly chamber was 7km from the portal. The water inflow made it difficult to get the materials to the machine," says Glen Maynard, Robbins Field Service site manager.

To overcome this, custom flat cars equipped with hydraulic lifts were used to transport the bigger sections of the TBM through the tunnel to the build chamber. Large sections of the TBM shield were positioned high enough to pass through the segment lining using the hydraulic lift and side shift adjustments as the cars passes through the tunnel. The Robbins machine began boring at a slight angle to the rest of the tunnel, bypassing the stuck machine before gradually meeting up with the original tunnel alignment.

"The section of tunnel from the launch chamber up to the point adjacent to the buried double shield was reasonably known due to the existing bored tunnel info," says Maynard. "We knew to expect large water inflows with flowing materials at any point over the initial 300m of tunnel."

In fact, the machine was required to be used in EPB mode as it encountered water pressures up to 23 bars, alluvium, flowing materials, and clay. Water pressure was lowered by draining the ground water through the rear shield probe drill ports, which were equipped with normally-closed ball valves. Probe drilling became routine after advancing 50m past the section that buried the original Double Shield TBM. The Crossover machine bored at approximately 30mm/min through the bad sections of ground, with any limitations in speed the result of the existing tunnel belt conveyor, which tended to have spillage issues resulting in significant cleanup. Despite the challenges, Maynard was proud of the accomplishment in the first section of tunnel. "We crossed through material that caused the double shield machine to become stuck. We bored 80m to the side of where that machine is currently buried and we passed it." To date, the machine has bored more than 25 per cent of the remaining tunnel length.

REDUCING RISK

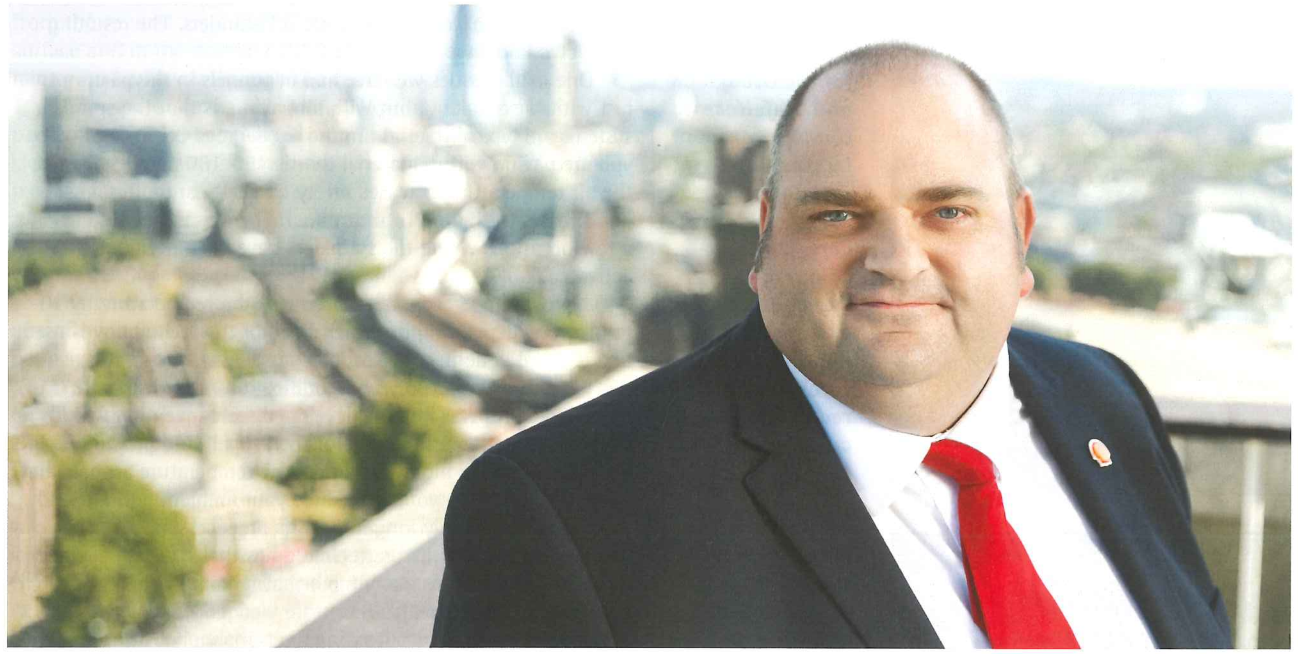
With projects like Gerede as an example of just how difficult Turkey's geology can be, how can contractors reduce risk? Bilgin says probe drilling is not something to be taken lightly in geology as challenging as the Anatolian Fault zone. "Most contractors try to avoid probe drilling since they think that this decreases daily advance rates, which is not definitely correct. However with careful analysis of the drilling data, it is possible to detect the problematic zones and take mitigation actions such as using an umbrella arch in front of the cutterhead and applying polymers." Bilgin additionally discussed a technology in development that could help with identifying major zones of failure. "We collected a huge amount of data from TBM tunnelling projects in difficult ground conditions in Turkey. In collapsing or squeezing zones we have observed a few key indicators like a critical peak of thrust/penetration or a change in thrust/torque ratio that serve as an indicator before the failure occurs. However, these changes are very sudden and sometimes it is difficult to detect. We are working on a computer programme for quick detection of these critical zones. I have to admit that this is not an easy task."

However he is optimistic that tunnelling in challenging conditions like those in Turkey will become easier over time. "Turkey's complex geology requires investing more on the side of ground investigation and on a custom, high-technology TBM. Contractors can reduce risk by employing a highly qualified and experienced tunnelling crew," says Bilgin. He adds that obtaining good service from a TBM manufacturer, and maintaining close cooperation among all parties involved, may be the most important risk reduction tools of all

Right: Specialised transport cars with hydraulic lifts were used to transport some of the TBM components through the tunnel and into the launch chamber

PUTTING ROADS TO WORK

Shell Bitumen is researching new technologies to make roads smarter – and it's asking the tunnelling sector to come forward with ideas. **Sally Spencer** reports



Above: ***John Read is keen to match new technologies with the needs of the tunnelling sector***

Sally Spencer
Sally joined the *Tunnels and Tunnelling* team as a contributing editor in 2015

ROADS TAKE US FROM A to B – that much we know. What most of us don't know, however, is that they also have the potential to convert heat to electricity, to provide a source of light, to monitor themselves for damage, to divert harmful particulates away from the breathing space above them and much more besides.

In fact, the concept of the 'smart' road is more than providing Wi-Fi access or being able to open up the emergency hard shoulder as an additional running lane in times of heavy traffic. Smart roads, as perceived by specialists such as Shell Bitumen can bring wide-ranging societal benefits.

And professor John Read, general manager technology (bitumen and sulphur) at Shell International Petroleum is on a mission to help society understand the full scope of what roads are capable of providing, both now and into the future.

Changing perceptions, he says will also ensure the company has "societal license" to continue its business in the longer term. To do this, he needs to engage with industry – and tunnelling is one industry sector in the cross hairs.

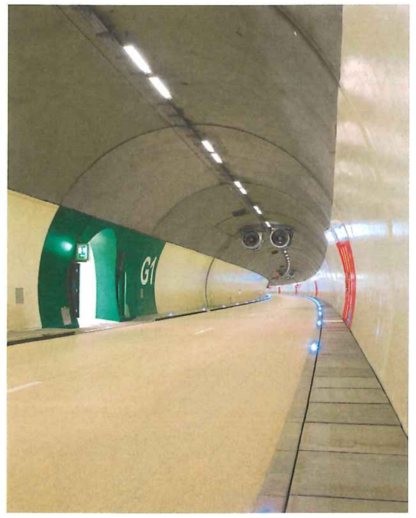
Currently, the typical tunnel road surface is essentially the same as any other, fulfilling the same safety and durability criteria. One key difference is the thickness of the road structure.

"Believe it or not, the only reason we build roads is because we can't drive on the mud – if we could, we would," says Read. "We build roads to protect the soil beneath and if you have weak soil you have to build very thick, strong structures in order to prevent them flexing and to enable them to carry heavy loads.

"In a tunnel you have a concrete tube, which is a great base to build upon, so the road structure can be very thin."

THINKING TUNNELS

That's not to say tunnels haven't featured



***Above:* Shell Bitumen supplied the road surface for the Grouft and Stafelter tunnels in Luxembourg**

***Left:* The light colour of the Mexphalte C LT is designed to improve road safety and to reduce lighting costs**

***Bottom left:* The lower working temperature of Mexphalte C LT results in a reduction in emissions**

innovative road surfaces and notable examples include those built with Shell's Mexphalte C.

"Mexphalte C came from our research and development programme," says Read. We developed a synthetic bitumen – it's not refined in the same way you refine bitumen but is synthesised out of other components to mimic bitumen rheology."

Recent applications of Mexphalte C include Luxembourg's Grouft and Stafelter tunnels. These tunnels – 2.96km and 1.85km respectively – link the capital, Luxembourg City, to the north of the country and opened in September 2015. The contract specified the use of a clear synthetic binder for the production of coloured pavements for the tunnel sections of the motorway.

"The old Henry Ford adage of 'you can have any colour you want as long as it's black' also used to apply to asphalt but colour can be used to demarcate areas," says Read. "Also, when we pigment Mexphalte C with titanium oxide it produces a whitening effect. When that is used with a light coloured aggregate, the net effect is a very light coloured pavement. And if you have a light coloured pavement you need less lighting."

This has obvious benefits in terms of reducing lighting maintenance and energy costs as well as improving safety.

In the Grouft and Stafelter tunnels the Mexphalte C was used in combination with another technology, which enables the production of low temperature (LT) binders. The resulting product is known as Mexphalte C LT.

"One of the issues we have had in tunnels in the past, not just with Mexphalte C, but with all paving, is that the sprinkler systems are typically set at around 60 degrees Celsius and when you are paving with a material that is 150-180 degrees Celsius the air temperature increases pretty quickly – and of course the hot air rises to the top of the tunnel. There have been quite a few occasions where the sprinklers have been accidentally activated."

The low temperature binder reduces the temperature by 30-50 degrees, depending on which form of the technology is used, and is a real benefit, says Read.

"We also brought polymer modification into Mexphalte C LT," he added. "This was initially developed for conventional roads in order to raise the performance of the asphalt and prolong its life. So we now have a highly modified low temperature asphalt that is light coloured, so you can reduce your ambient lighting and that lasts significantly longer than its predecessors."

Mexphalte C and LT are technologies that have already been adopted but there are many more that remain in Shell's research and development pipeline. Some are wedged there because of the absence of a clear route to market or simply by government bureaucracy.

RESEARCH AND DEVELOPMENT

Certainly Read and the R&D team at Bangalore (a newly opened, purpose built research facility that will eventually house up to 1,500 researchers in a state-of-the-art campus environment) are focused on extending the use of roads beyond their principal purpose of linking A to B. And the line the research takes is usually prompted by a series of "what if...?" questions.

"As an example, asphalt is usually black and it is well known that black absorbs heat," says Read. "One of the reasons roads fail is through permanent deformation or rutting that occurs when it is very hot, because of the viscoelastic nature of bitumen. If you can take that heat away you can improve the longevity of the road – and heat is a form of energy so can you do something with that energy?

"There have been different ways of thinking. One was to create a big reservoir of water, which could be heated from the heat taken from the road and either used to drive a turbine or to provide hot water for people's homes.

"That would offset the cost of generating electricity but the other thought was, could we convert the heat directly to another form of energy? Our research scientists found they were able to do that and demonstrated that they could generate seven watts per square metre. That might not sound like much but when you consider the number of square metres in a road system it becomes very big, very quickly."

Another major problem associated with road use that has been under the Shell spotlight is air pollution. The boffins at Bangalore have developed two technologies capable of addressing this issue, Active Active Asphalt and Passive Active Asphalt.

"A road surface is typically neutral or, if anything, slightly repellent to PM10 particulates that come out of exhaust fumes, so it either does nothing to them or pushes them slightly up into the air where they are suspended and people breathe them in," says Read.

"We asked the question, was it possible to alter the charge of the road surface so that, rather than repelling, it actually attracts PM10 particulates?

"And that's what we did. We developed a technology using a special type of fibre incorporated into the asphalt that physically changes the polarity of the surface so that PM10 particulates from the exhaust are attracted to it. They then sit on the road surface and in the normal course of events are washed away by rain or pushed away through the channels of the road."

In the case of a rain-free tunnel, Read anticipates the particulates would be removed from the road surface by periodic cleaning or would be dragged out on the tyres of vehicles passing through.

"This is the theory," he says, however. "We haven't tried it in a tunnel yet."

This development provided a stepping-stone to the next.

"The type of fibre we used is also electrically conductive, so one of my bright sparks had the idea of finding out what would happen if we actually placed a charge across the material.

"We made a big slab of the material in the laboratory, put a clear polythene bag over it, filled it with smoke and applied a charge. It cleared instantly – everything was attracted to the road surface.

"So we ended up with two forms of the technology. One was called Passive Active Asphalt, which was just conventionally laid on the road and it would attract particulates because of the change in the charge at the road surface and the other, called Active Active Asphalt, would clear particulates immediately if the charge was increased massively by placing an electric charge across the material.

"Our view was that this would be a fabulous product for tunnels," says Read. "Wouldn't it be great if, instead of having to have enormous ventilation systems and huge fans drawing [the pollution] out, you could just flick a switch once an hour and clear the air?"

Passive Active Asphalt was trialled in Trondheim in Norway in the late 1990s. Two parallel sections of the road were laid, one with conventional asphalt, the other with Passive Active Asphalt.

"It was a misty day with mist right down to the ground, you couldn't see Trondheim at all," says Read. "But when we'd laid the Passive Active Asphalt there was a 6ft [1.8m] gap between the road surface and where the mist started and you could see Trondheim perfectly clearly. On the other side, with the conventional surface, the mist was down to the ground.

"The Passive Active Asphalt had clearly worked. In this case it had attracted water particles instead of PM10 particulates, but it demonstrated that the change in charge actually worked."

So why aren't the obvious benefits of these road surface technologies in evidence today?

"The trial looked fantastic but then unfortunately all sorts of political changes happened in Trondheim and the surrounding area and for one reason and another we weren't able to go in and monitor the road, even though we had built it," says Read. "So I don't know whether that was an instantaneous effect or whether it was something that would have lasted the entire lifetime of the pavement. And I don't know whether it would have attracted 1 per cent of PM10 particulates or 99 per cent of them."

***Above:* A bitumen sample is stretched in the laboratory for force ductility measurement**

It wasn't just Trondheim that threw up barriers to advancement in road surface technology and while bright ideas and nascent technologies abounded, there was no clear route to market.

"Shell is quite an altruistic company but there comes a point when you have to say, if we can't make any money out of this, we have to stop and do other things. So all this work was put on the shelf and we re-focused our research."

ATTITUDE SHIFT

Around two years ago, however, Shell noted "a sea-change in attitudes".

"The previous blocks didn't seem to be there anymore. Highways England [formerly Highways Agency] had been formed as a ring-fenced governmental company that could make its own decisions about whether it wanted to run with this type of innovative technology."

Attention and subsequent legislation is also increasingly being directed towards improving air quality by reducing emissions.

"There has been a lot of legislation around the world with regards to emission standards and sustainability. However, it tended to only impact very big companies and major manufacturing sites, such as refineries. They didn't ever really apply to a single asphalt plant, for example.

"But now, in Switzerland, they do and suddenly there has been a fiscal imperative to start to use more low temperature technology, to start to use more recycled material and so on in order to avoid paying a carbon tax."

There is equal emphasis on lowering emissions elsewhere in the world. China is a prime candidate for technology that helps manage air quality, for example and in major cities such as London there is talk of applying levies to "toxic cars".

"Everywhere you look you can see

fiscal drivers being put into place that will enable innovative technology to be brought in," says Read.

He added that, at a worldwide political level, some traction had been achieved on action against air pollution.

"COP21 [the 2015 United Nations Climate Change Conference] was the first time China and America, the two biggest road builders and consumers of bitumen in the world signed up [agreed to limit greenhouse emissions]," he says.

The other, equally fundamental change in attitudes, says Read, relates to cost. Those people who have wanted to wear the sustainability badge but have baulked at the cost are now more willing to consider paying the price.

"I've been working in this sector for 32 years now and this is the first time I have felt that attitudes are aligning with these new technologies and there is a chance of success," he says.

"Mega-trends", such as reducing global emissions, are now driving some of Shell Bitumen's research, as are specific requests from industry.

"The development of low temperature binders was a response to questions from industry," says Read. "The emissions from asphalt are a rate controlled reaction – so for every 10-12 degrees Celsius you can drop the temperature you halve emissions. If you can reduce the temperature by 30 degrees you can reduce your emissions eightfold – it's as simple as that."

He added, however, that the reduced emissions were almost a bonus and that what had really driven the LT development was the fact that operating at lower temperatures meant the asphalt plant used less fuel and saved money.

"Yes, there was a cost in making the binders low temperature but it was more than offset by the savings in fuel. On top of that there was the benefit of sustainability, and that is why that particular technology took off in the last decade when all the others didn't."

Many more development ideas are springing from the blue sky thinking Read encourages the Shell Bitumen research team to engage in.

One idea being looked at is the possibility of charging electric vehicles as they travel, rather than at static charging points.

"I know that Highways England wants to run trials to see if there is a way to be able to pass an electric charge through the roads that would charge a vehicle as it drives. We know we are able to convert heat from the road to electricity, so if we can convert that to electricity in the road, can we use the road itself as a charging body?

"This is just one of the ways we may be able to extend the work we have already done, increase its value to society and overcome the initial cost hurdle. You may be able to say to people, 'you have to pay a bit more for the roads but you don't need to fill up with petrol, you just charge your vehicle as you drive'. I think it would be quite an easy sell."

Of course, even if the technology was available today, it could only exist in a patchwork system because replacing the road infrastructure takes decades. Resurfacing on the major network is every 14-20 years, while for the rest of the road network it is every 80 years.

However, Shell's scenario planning looks up to 100 years in the future and for this particular potential solution it is thinking about what the roads of 2050 will look like.

"Yes, it's a long time in the future, but it is all grounded in developments that are being made today," says Read.

Staying with electricity, other research is looking at the applications of piezoelectrics. Shell has worked with Pavegen, a company that has developed kinetic tiles that capture the energy of footsteps and convert it into electricity.

In Rio some lucky children are now able to play football in the evenings thanks to free floodlighting powered by electricity created by their own footsteps on the pitch during the day.

Aside from fostering the talents of Brazilian footballers, the piezoelectric technology is now being conceptualized as a means to inform local authorities and or contractors when a road is failing. As a road deforms or cracks, the piezo would give out a higher electrical current, which could then be converted as an indication of damage – it would be a really 'smart' road.

"Wouldn't it be great if, instead of having to have vehicles constantly travelling around assessing the road condition, the network could tell you itself?" Read asks.

But that's just an initial thought. Taking it a step further, could piezos generate enough electricity to run, not just half a dozen floodlights, but enough to feed into the grid?

"We just don't know," says the ever-candid Read. "We clearly know that roads move every time a vehicle travels over it and that would generate a charge, but whether or not that charge when done millions and millions of times would be enough to warrant the cost of generating electricity, we don't know."

Another "warning" technology in development is a phosphorescent binder, which absorbs light during the day and releases it at night, and which could be

Above: ***Observing a bitumen drop before microscopy at Shell Bitumen***

Below: ***A Shell Bitumen research scientist observing the bitumen polymer network*** used to imprint signs on a road. And another includes a system using Mexphalte C, which changes colour when the temperature drops.

"If the road is freezing it would change colour to warn drivers to take extra care," says Read. "This would certainly be useful at the entrance and exits of tunnels."

Meanwhile, titanium oxide, which reacts with nitrous oxides in the atmosphere to form nitrates that fall to the road surface to be washed away is being added to create "DeNox" paving.

R&D ideas are clearly coming thick and fast and the start of 2017 saw Read's team begin a new three-year cycle in which all the aforementioned technologies have been taken down from the shelf and are back in the research domain.

"One of the questions we are looking at is whether we can improve the delivery system, so that we can apply them to existing roads and tunnels without having to rebuild the entire structure. Another question is whether we can combine technologies.

"Certain things we know we could combine, but not everything. For example, we know we could apply the phosphorescent road surface technology alongside or inside Mexphalte C because that was the original delivery system developed for it.

"What we don't know is if the ambient lighting in a tunnel would charge the photochromic pigments that we use to get the phosphorescent effect. Could a system work in a tunnel where the lights are turned on for half the time and that charges the road surface sufficiently for you to then turn the lights off for the other half, reducing the cost and the environmental impact of running the tunnel?

"Can we make a conductive asphalt with Mexphalte C LT and use the electricity generated in it to power the already reduced lighting resulting from the light surface? I don't know. We would need to work with someone to trial that. Can we use Active Active Asphalt for tunnels and see if we can really clear the air and reduce the amount of ventilation needed? I don't know because we have only looked at it in the laboratory so far."

Read is convinced that some of these technologies, or combinations of them, will be suitable for tunnels but what is needed now is more industry engagement to turn some of the questions into answers.

Thus far, Shell has had very little engagement with the decision makers within the tunnelling sector and that is something Read is keen to address – hence the call out to the industry in *T&TI's* February issue.

A closer relationship would not only lead to further laboratory and field tests, dialogue would also ensure the company was aware of issues and opportunities to provide solutions.

"Our customers are asphalt suppliers and while they speak to a main contractor, who then works with a tunnelling contractor, we are so far removed that we don't know the correct routes to be able to have the necessary conversations.

"I know we already have products that we know work in tunnels and I know we already have products that we think will work in tunnels but I currently have no conduit to have those discussions. I think it would be beneficial to at least be able to understand what the true needs are and what we can do to help address them. It may be a lot, it may be a little – I just have no feel at this point because we don't have those sorts of engagements."

As an example, a recent conversation turned to fire protection.

"We're not working on anything at the moment but we have developed fire retardant bitumens for the roofing industry in the past, because it has to meet very stringent fire regulations, just as the tunnelling industry does.

***Above:** World bitumen demand is between 95-110 million tonnes - 70 per cent of this goes into roads*

"We could possibly use or adapt the technology we have already developed but we would have to look at what difference it would make versus how much it would cost. We do have solutions but we've never applied them in a tunnel. And this is exactly why we need to engage with the sector because we don't necessarily know what its concerns and needs are."

Ask Read what he thinks would constitute the perfect tunnel road surface and aside from the obvious "anything that contains Shell products", he suggests combinations of light coloured and phosphorescent materials that would minimize the need for artificial lighting; porous, rather than dense, material that can absorb noise; and conductive material that can generate electricity to power any ambient lighting and ventilation that is needed.

"And if you could combine those with Active and DeNox technology so you can take PM10 particulates and nitrous oxides out of the air and improve the user's experience of being in a tunnel, then that would constitute a perfect road surface.

"But – at this moment I don't know if you can combine all these things and I don't know if all of them can work in a tunnel. So, in fact, I don't think the perfect road tunnel surface exists or has even been thought of yet.

"There is work to do"

***Below:** Shell's scenario planning envisages much smarter roads in the future*

SYSTEM UPGRADE

The Mont Blanc Tunnel hosts 1,600 people a year for tours of its structures and systems and is very focused on its operational side. Recently, the concession-holders have implemented a new safety and security system, Logos

Alex Conacher
The *Tunnels and Tunnelling* editor has been with the magazine since 2010

TEAMS AT THE MONT Blanc Tunnel are excited about a new centralised control system for safety and security equipment. Called Logos, which is a French acronym for 'localise, organise and manage security operations', it makes use of tens of thousands of data points along the tunnel and can store many times more data than the previous system. It also automates a lot more actions, allowing security teams to respond quickly "after a few clicks of the mouse" according to a spokesperson for the owners. The system has been implemented at a cost of EUR 4M (USD 4.5M) by joint concessionaires Mont Blanc Autoroutes and Tunnel (ATMB) for France and SITMB of Italy. The new system is connected to the control tower – a command and control centre – where 22 operators working in shifts round the clock control all the tunnel's security equipment, from ventilation and barriers to rescue team alerts.

The system constantly analyses 36,000 security-related data points received from 157 cameras and 4,000 sensors placed throughout the tunnel. It detects, analyses and warns of any abnormal situations, for example if a car has stopped inside the tunnel or a higher risk event has taken place. It is capable of making 11,000 pieces of tunnel operational equipment interact with one another so that operators can decide on and launch the appropriate response for a given situation, for example turn on the ventilation system, lower barriers, or to alert rescue teams or other emergency services.

More operations have also been automated in Logos, such as set radio calls and message dispatching. It features an updated interface designed to keep operators more focused on security actions and decision-making.

Below: ***The command and control centre***

DATA-DRIVEN TRAINING

The system can also store 36 times more data than the previous setup, which provides what might be an unexpected benefit – a training aid. Tunnel teams undergo training drills on a daily basis at the Mont Blanc Tunnel; the new storage capacity allows the system to save real-world events, for example the effects of a broken down vehicle, that can then be used in simulation exercises for response units and operators. This also allows for easier information-sharing with other operators.

A spokesperson adds: "The old system was already a centralised system for the remote or manual monitoring and control of field equipment in the tunnel. This system, which was particularly cutting-edge for that time, used technologies that were tried and tested at the end of the '90s and offered tunnel management functions, some of which have been reinstated in the new system. The new system makes use of the latest technologies (for example: storage capacity or server virtualisation) and offers much improved performance compared with the previous system.

"All the operators have also followed a 40-hour training protocol to prepare them to use Logos as soon as it is launched. The new man-machine interactions (MMI) were the subject of an ergonomic study and were designed by a graphic designer.

"The outcome: better detection of abnormal situations, quicker access to the control buttons, reduced eye stress, to mention but a few."

Facts and figures

- Incident detection: The 22 traffic security operators working shifts 24/7 in the tunnel's "control tower" have three missions: control traffic, manage security equipment and report traffic conditions.
- Real-time traffic management and user information: 70 km speed limit, 150-metre spacing between vehicles monitored by Binational Police officers, 40 lighted information signs, 120 traffic lights and 40 half barriers every 600 metres, 12 FM channels.
- User protection: 116 safety rooms and 37 shelters measuring 40 m^2 every 300 metres that are hermetically sealed and supplied with fresh air. They include equipment like a videophone and drinking water. The shelters are connected to an underground evacuation passage along the entire length of the tunnel.
- **Firefighting facilities and immediate response stations:**
- Twelve firemen are stationed round the clock at each end and in the middle of the tunnel ready to deploy a Proteus truck, the only model of its kind in the world.
- There are 76 fans that can exhaust 150 m^3 of smoke per second every 600 metres.
- **Expert teams and routine training:**
- Over 260 people are assigned to the 11.6 km tunnel, including 70 firemen.
- Four simulated security drills are organised every year
- Response teams receive a total of 3,500 hours of additional training annually.
- **Major investments for the best and most innovative equipment**
- In addition to the €400 million investment to reopen the tunnel in 2002, €59 million was spent to keep security facilities in Mont Blanc Tunnel constantly upgraded with the best technology.

TESTING

In 2012, teams at GEIE du Tunnel du Mont Blanc began a complete overhaul of the control system with an objective of using the latest technology. Based on feedback collected from 10 years of practice and operations, teams working on the tunnel compiled a list of new functionalities for the system.

After a phase for development and testing in the plant, the teams spent a year testing the new system starting at the end of 2015. The rollout required one million tests, including 12,000 under real-life conditions during the 25 nights the tunnel was closed. For this testing phase, teams used a simulator to train.

COMPLIANCE

In accordance with the requirements of the GEIE project team of the Mont Blanc Tunnel, the safety functions of Logos have been designed and developed so as to achieve Safety Integrity Level (SIL) 2 laid down in the international standard IEC EN 61508, based on which the software was certified by RINA Services, the leading certification company in Italy. The International IEC EN 61508 standard regulates the design and operation of electrical, electronic and programmable electronic safety-related systems for those sectors likely to present a risk to people or the environment or where a loss could be incurred.

FULFILLING THE CONTRACT

In order to meet the requirements of the specifications, the Italian company Giordano & C., which was awarded the contract, designed and developed a computerised system based on the monitoring software systems of Wonderware (a company of the Schneider Electric Group), for distributed architecture and the virtualisation of servers.

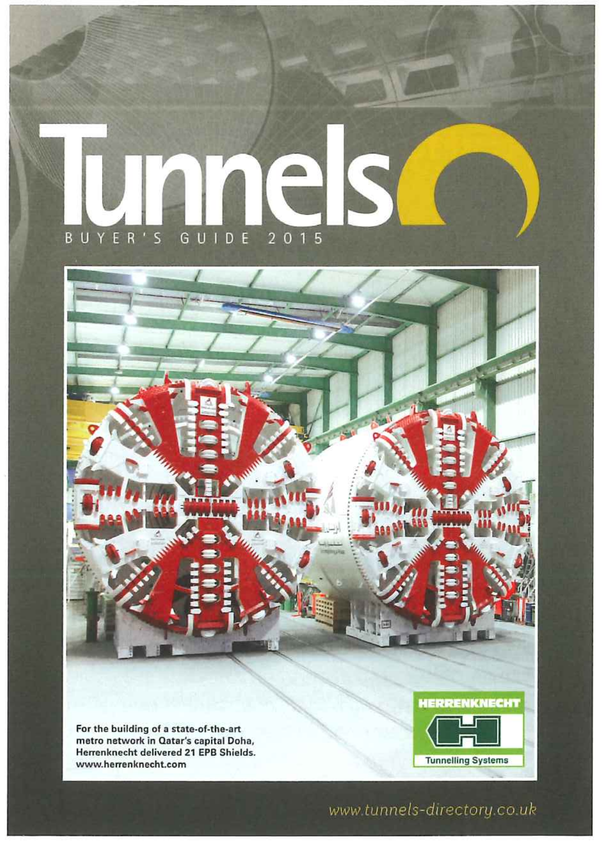
The IT resources needed for its functioning are distributed on the French and Italian platforms of the tunnel and communicate with each other via a network of optical fibres dedicated to monitoring. The data can therefore be sent from one end of the tunnel to the other within less than 300ms and, because the architecture offers several redundancy levels, it guarantees the high degree of availability of the system. "By improving the centralised system's performance, we are increasing response time for operators. This new tool is the culmination of human and technical performance. Twenty people were mobilised for the entire duration of the project," says Cédric Petitcolin, project manager in the technology and IT department.

FINAL THOUGHTS AND FIRE ENGINES

According to the owners, the need to keep up with technological changes was the main reason for the upgrade, although they wanted to have new functionality for their operators, such as the automated actions, speed and use of data, and remote-controlled systems.

The teams also told *Tunnels and Tunnelling* that they wanted to mention their new pride and joy, a redesigned fire engine called the Proteus. Not everything is software.

It has been produced in cooperation with tunnel crews and boasts a 12,000 litre reservoir with enough pressure for 20 minutes, two hoses with variable spray guns for a range of 60m, a "start and go" button on the side of the vehicle that immediately turns it on and saves firefighters precious time, infrared cameras, next-generation radar and an extra-low cab so the truck can be driven under any visibility conditions. It has replaced the Janus truck, which was introduced with the reopening of the tunnel in 2002



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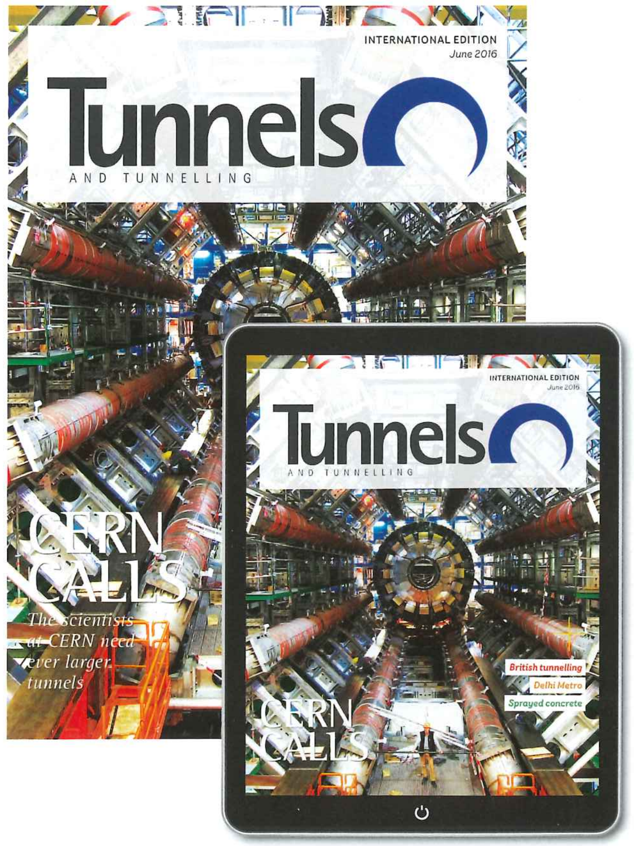

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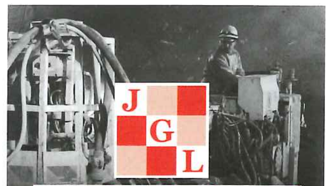


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What's on

2017

Swiss Tunnel Congress
30 May - 1 June
Lucerne, Switzerland
The Swiss Tunnelling Society organises the annual Swiss Tunnel Congress at the KKL Lucerne. During the last few years, this annual STS event has developed into the main congress for tunnelling experts in Switzerland, originally evolving from the AlpTransit congresses. There are usually around 800 experts from 15 nations attended the high quality presentations and additionally enjoyed the traditional excursions to large construction sites within Switzerland and the surrounding area which took place.
www.swisstunnel.ch/en/swiss-tunnel-congress

Rapid Excavation and Tunnelling Conference 2017
4-7 June
San Diego, California
The Rapid Excavation and Tunnelling Conference is the only conference with a dedicated focus on the developments, technology, trends, and innovations that directly affect the tunnelling and underground construction industry. It is a premier event.
www.retc.org

World Tunnel Congress 2017
9-16 June
Bergen, Norway
The theme of the 2017 World Tunnel Congress, which returns to Europe this year, is 'surface problems - underground solutions'. The Norwegian tunnelling industry produces tens of kilometres of drill and blast tunnel every year through the complex topography of this Nordic country.
www.wtc2017.no

Geo M East 2017
15-19 July
Sharm El-Sheik, Egypt
Recent and rapid construction investment in Egypt has provided great opportunities for tunnel engineers to use their knowledge and talents to solve many challenging problems using innovative solutions and cutting-edge technologies.
www.geomeast2017.org

ICTUS 2017
28 August - 1 September
Seoul, South Korea
The Korean Tunnelling and Underground Space Association welcomes you to Seoul. The theme is "Frontier Technologies in Tunnelling and Underground Space Technologies". It will play host to these sessions: innovations in mechanised tunnelling, developments in UG space tech, improvements in conventional tunnelling, structural and hydraulic interactions, extreme conditions, and stability.
www.i-asem.org

Shotcrete for Underground Support XIII
3-6 September
Irsee, Germany
SUS XIII aims to pool the consolidated efforts from engineers, researchers and project managers from across the world in order to share and update state-of-the-art technology and best practices in rock engineering, rock support methods, TBM tunneling and deep excavation.
www.engconf.org

International Symposium on Aerodynamics, Ventilation & Fire in Tunnels (ISAVFT 2017)
13-15 September
Lyon, France
Tunnel ventilation is a small part of the cost of a tunnel, however, it is often crucial for sizing the civil engineering works, and in allowing a given type of traffic. There is pressure upon designers and engineers to develop more cost-effective solutions for tunnel construction without compromising safety. This has been the premier international event providing delegates with opportunities to discuss new research and developments. An essential diary date for everyone in tunnelling.
www.bhrgroup.com

Underground Infrastructure of Urban Areas
24-26 October
Wroclaw, Poland
This ITA endorsed conference is being organised by Wroclaw University and the Polish Tunnelling Group. The conference will cover the theme: "discussion on problems related to underground Infrastructure".
www.pbp-ita.pl/.org

TBM Digs
16-18 November 2017
Wuhan, China
Following the success of the first two TBM Digs events, the conference returns for the third time. This year it heads to the city of Wuhan in China's Hubei Province.
www.tbmdigs.org

Stuva Expo 2017
6-7 December 2017
Stuttgart, Germany
The 2015 trade fair accompanying the Stuva conference exceeded all expectations. With 1,850 conference delegates and more than 550 trade visitors, around 2,400 visited in 2015 and the 2017 event is expected to build on this.
www.stuva-expo.com/en/

2018

NASTT No Dig 2018
25-29 March
Palm Springs, USA
Since 2001, this show has nearly doubled in size, keeping pace with the rapid growth of our industry. Cutting-edge technologies are continually being developed and introduced, see them at the largest trenchless technology show.
www.nastt.org

World Tunnel Congress 2018
20-26 April
Dubai, UAE
The World Tunnel Congress heads to the United Arab Emirastes in 2018, and demonstrates the rise of the Middle East to the centre stage of the global tunnelling market. The organisers invite you to experience true Arabian hospitality and enjoy Dubai, which claims to be the world's most cosmopolitan city.
www.uaesocietyofengineers.com

North American Tunnelling Conference
24-27 June
Washington D.C., USA
The NAT is the premier biannual tunneling event for North America, bringing together the brightest, resourceful and innovative minds in the tunneling industry.
www.natconference.com

11th International Conference on Geosynthetics
16-21 September
Seoul, South Korea
The technical program will include a Giroud lecture, 5-6 plenary lectures (special lectures), 2-3 short courses and approximately 50 parallel sessions.
www.11icg-seoul.org

10th Asian Rock Mechanics Symposium
29 October-3 November
Singapore
Asia is witnessing the greatest growth and demand in the world for infrastructure and resource development. According to Asian Development Bank, approximately US$8 trillion needs to be invested in overall national infrastructure before 2020, 68% of which is for new capacity. Certainly, rock mechanics and rock engineering will have a critical role to play in many of these infrastructure and resource development projects. The theme for ARMS 10 is "Rock Mechanics in Infrastructure and Resource Development".
www.arms10.org

2019

World Tunnel Congress 2019
3-9 May
Naples, Italy
The one tunneling event that is unrivaled in its international reach. The World Tunnel Congress is coming to Italy and tunnellers representing owners, contractors, engineers and suppliers will be exhibiting. The event is expected to attact as many as 600 technical papers, 250 exhibitors and up to 3,000 attendees.
www.facebook.com/events/1753343481565751/

ECSMGE 2019
3-9 May
Reykjavik, Iceland
The Icelandic Geotechnical Society are pleased to welcome you to the XVII European Conference on Soil Mechanics and Geotechnical Engineering, held in the Icelandic capital. The theme of the conference is "Geotechnical Engineering, foundation of the future" and will embrace all aspects of geotechnics.
www.ecsmge-2019.com

The British Tunnelling Society

The BTS has a membership of over 814 individual and 266 corporate members. It is one of the most vibrant gatherings of professional tunnellers in the world and traces its history back to its founding in 1971. Regular BTS monthly meetings are hosted at the Institution of Civil Engineers in London from 5.30pm every third Thursday of the month. In recent years, the BTS Young Members (BTSYM) group has also begun hosting its own events.

Paddington Bakerloo Line Link Project
15 June 2017
The meeting will describe Transport for London's / London Underground's Paddington Bakerloo Line Link project and cover such aspects as: the Sprayed Concrete Lining works, the cross passage excavations, the new switch room excavations, the link tunnel breakthrough with secondary lining, the square works in the lift lobby and the lower concourse strengthening.
Speakers: The CSJU / LU delivery team

BTSYM: Challenges in the drilling and blasting method at the main access tunnel for the Uma Oya Project
7 September 2017
The Uma Oya multipurpose project is a hydropower project in Sri Lanka with several tunnels over 25 km in length, mostly in hard rock. This presentation will describe some of the challenges and solutions in the Drilling and Blasting method used in this project during construction. Excavation of the underground powerhouse complex and associated tunnels will be explained and improvements in the drill and blast patterns implemented will be described.
Speakers: Mehdi Hosseini, London Bridge Associates

High Speed Railway Tunnel Projects & General Tunnelling Status in China
21 September 2017
This presentation will be given by the China Railway Tunnelling Group Contractors & China Railway Engineering Equipment Group. It will discuss the status of high speed rail technology in China with a particular emphasis on the design, construction techniques and use of TBMs in the tunnel sections of current major projects. An overview will be given of how the roles of client, designer and contractor operate in the Chinese market. The presentation will cover the past, present and future of high speed rail in China.
Speakers: Kung Wang and Yali Han

Finsbury Park Squareworks
16 November 2017
A presentation on the Finsbury Park Station step-free access scheme for London Underground. This will include information on squareworks tunnelling, shaft sinking and undertrack crossings, all carried out from within a live station.
Speakers: Farid Achha, London Underground; John Elliott, Alan Auld Engineering; Menelaos Lydakis, C Spencer Group

Waterview Tunnel, New Zealand
14 December 2017
The Waterview Connection in Auckland, New Zealand is the largest and most complex road project ever undertaken in New Zealand. The project involves two tunnels, each three lanes, with an outside diameter of 14.41m excavated under residences, the Great North Road, and Auckland's western rail corridor.
Speakers: TBC

If you have a topic or project you feel would be suitable for a BTS evening presentation, please contact:

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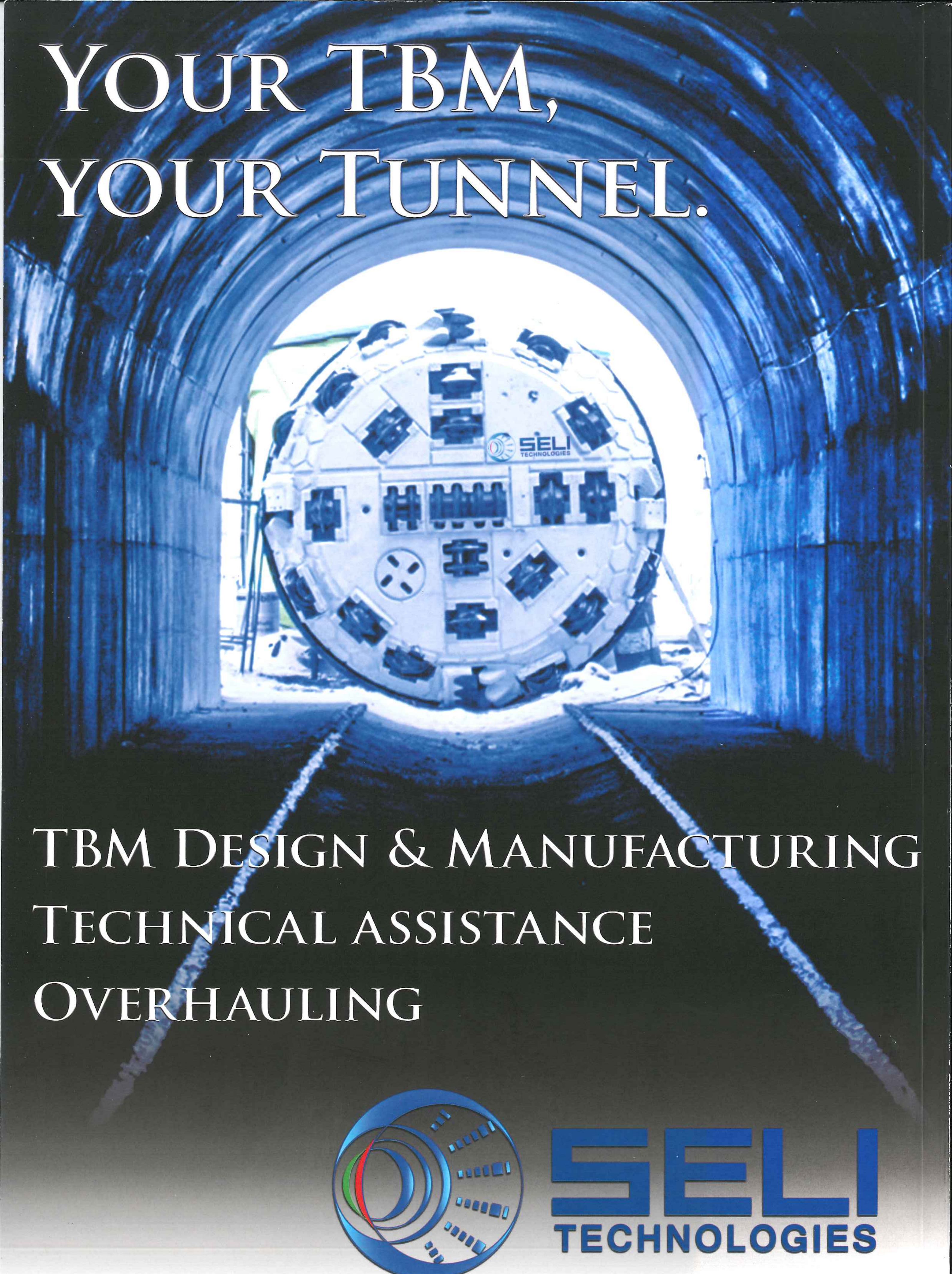

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