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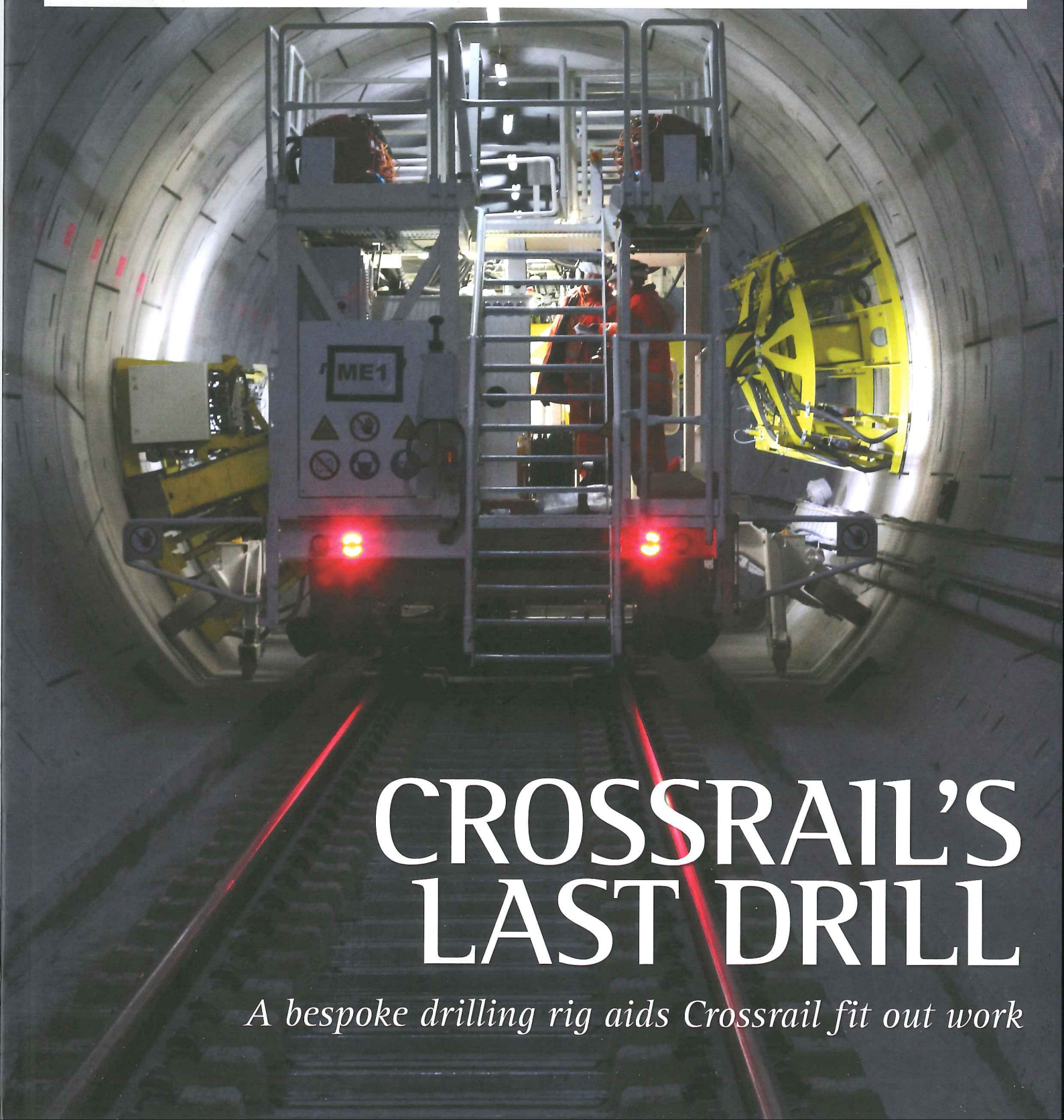
February 2017

Tunnels AND TUNNELLING



CROSSRAIL'S LAST DRILL

A bespoke drilling rig aids Crossrail fit out work

PEAK DEMAND

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

The fourth and final unity of the Ingula Pumped Storage Scheme recently went into commercial operation. Most readers will be aware of the need for schemes of this type, but it is interesting to sit down and think about the sheer importance of the end-use of what tunnel engineers are building.

Getting the world to kick its dirty energy habit is not just about building more nuclear power plants, further developing photovoltaic technology or even the heavy taxing of undesirable fuel sources.

One of the biggest challenges to keeping the network green is the enormous variance in daily energy demand. Some events cause such an incredible strain on the network that they must be planned for a long time in advance. As an example, British Gas releases UK energy usage statistics during major sporting events. A relatively major event, New Zealand vs. France in the 2011 Rugby World Cup final caused demand to hit 420MW, while England vs. West Germany in the 1990 Football World Cup saw a surge to 2,800MW.

The problem is that a lot of green energy sources are temperamental and often out of sync with peak energy demand. There is no solar generation after sunset, for example. The green sources that do work consistently, i.e. nuclear generation, take a long time to start up and shut down, so they are not the best suited for hitting peak demand. Although they are a very good option for meeting the base demand if the price is right. To meet peak energy demand, we rely on rapidly activating but dirty fossil fuels. The question for green energy then is how to bring peak generation in line with peak consumption. The answer: storage.

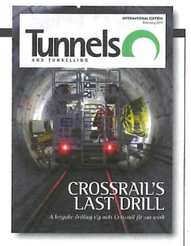
Dr Steven Novella who hosts the science and critical thinking podcast 'The Skeptics' Guide to the Universe' recently tackled the various options (see episode 597).

Aside from the familiar pumped storage, Novella highlighted recent discussion of cryogenic storage. This uses energy to liquefy air, compressing it 700 fold. The subsequent expansion into gas turns a flywheel.

In pure theory the various methods can be judged on their 'round trip efficiency' (RTE), which is the percentage of energy lost after energy is put into storage then sent back into the grid. An article on by energy manager and engineer Tom Lombardo on Engineering.com quotes numbers from HPS, a designer of cryogenic storage systems, which claims for its product "a 50% RTE, which they hope to increase to 80%. By comparison, batteries are 60 to 70% efficient, pumped hydro is 75% to 85% efficient, and compressed air energy storage is 45% efficient."

As it stands for energy storage, particularly with the limitations of batteries, a tunnelled solution is king

Cover
The cover shows the Rowa drilling machine in use on the Crossrail project in the UK's capital, London



Next issue
In the next issue of *Tunnels and Tunnelling International* we have an article on VMT's new deformation monitor, a report from the Albabstieg tunnel in Germany, a look at Israeli burial tunnels and a report from the Underground Solutions seminar

This month...

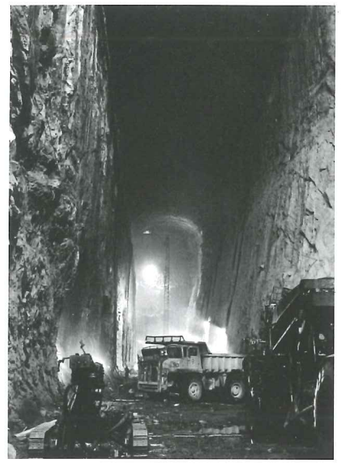
10 YEARS AGO

Low driver patronage and wrangling over tolls and local road closures has led to the collapse of Cross City Tunnel Motorway, the concessionaire operating Sydney's Cross City toll tunnel. Insolvency specialist KordaMentha has been appointed receiver and manager of the tunnel on behalf of a syndicate of 16 domestic and international banks owed US$439M from the project. The company has a 35-year concession to build and operate the tunnel. The 2.1km long toll tunnel opened in August 2005 but traffic volumes have been about a third of forecast levels of 90,000 vehicles a day. Drivers initially boycotted the tunnel because of the high tolls, and there was a public outcry over about 70 road closures that forced vehicles to use the tunnel.
Tunnels and Tunnelling website, February 2007

40 YEARS AGO

Drifter wonders what 1977 has in store for the industry. Looking back on 1976 we can almost be forgiven for not having much hope. The frustrations of inflation and sporadic labour unrest have hit Britain particularly hard. We appeared to be both ill-equipped and ill-prepared to cope with either, nor could we find consolation in learning that the Australian and East Coast Americans have suffered longer and harder from this effect of restrictive practices of disorganised labour. However, Drifter sees hope in associations of people of common purpose internationally.
Tunnels and Tunnelling, February 1977 p.19

Groundwater infiltration, page 18



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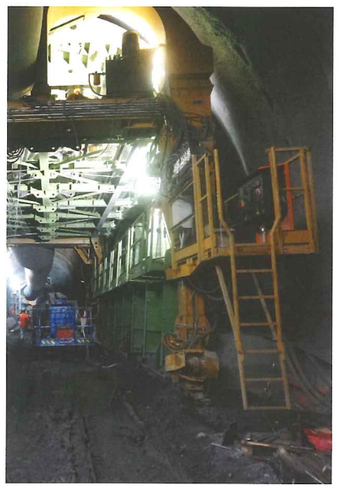
Rowa's drilling rig, page 23



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ATLAS COPCO COULD SPLIT IN 2018

SWEDEN — Tunnelling machinery manufacturer Atlas Copco has begun working towards splitting its business. It will present the proposal to form Atlas Copco and "NewCo" which it said is a working name.

NewCo will focus on the mining and civil engineering sectors and include the existing Mining and Rock Excavation Technique business area and the Construction Tools division with related service operations. This business has approximately 12,000 employees and had pro forma revenues of SEK 28bn (USD 3.2bn).

Atlas Copco will focus on industrial customers and include the compressors, vacuums and industrial business areas plus its portable energy division, including service, and the specialty rental division. This business has approximately 33,000 employees and revenues of SEK 74bn (8.45bn).

If the shareholders decide in favour of the proposal, the split of the Group is planned to be done through a share distribution, whereby Atlas Copco AB's shareholders will receive shares in NewCo AB in proportion to their existing shareholding. The intention is to list NewCo AB on the Nasdaq Stockholm stock exchange in Stockholm, Sweden, in the second quarter 2018.

"The Board and Management believe that long-term shareholder value will be created by splitting the Group into two separate companies," said Hans Stråberg, Chair of the Board of Directors of Atlas Copco AB.

"Both businesses are global leaders in their respective fields and will benefit from a more focused management responsibility."

"The two businesses have different demand drivers and demand characteristics," said Ronnie Leten, President and CEO of the Atlas Copco Group. "A split will increase their respective abilities to add value to customers, grow the business and attract talent."

Abu Dhabi eyes knowledge sharing

UAE — The Masdar Institute of Science and Technology has signed an agreement with the Abu Dhabi Sewerage Services Company (ADSSC) to share knowledge and research to help build safe and sustainable tunnels in the region. The deal is due largely to work on the Strategic Tunnel Enhancement Programme (STEP).

Al Yousuf of the Masdar Institute said: "Rapid urbanisation in the UAE demands the development of more underground infrastructure like pipelines. However, the environmental impact of underground construction is substantial.

"That is why it is important to develop a robust knowledge base to ensure that underground infrastructure projects are developed in a way that balances between meeting growing infrastructure needs and preserving the environment."

Al Dhaheri, deputy managing director of ADSSC said: "This collaboration with Masdar Institute supports the ADSSC's goal to proactively coordinate with relevant authorities in order to deliver infrastructure to the highest standards while enhancing sustainability."

This collaboration will enable Masdar Institute students to receive hands-on training in the field, with access to ADSSC project sites like the STEP site, which will in turn support the development of a cadre of highly-skilled tunneling experts who will be critically needed as rapid urbanisation will place greater demand on underground infrastructure.

Speaking about Masdar Institute's research experience in the field of underground tunneling, Rita Sousa, Assistant Professor of Mechanical and Materials Engineering, said: "We have already developed a novel software program in collaboration with the Massachusetts Institute of Technology (MIT), which is composed of different tools that allows optimal planning, design and construction of tunnels while considering different sources of uncertainties that are inherent when dealing with the underground. The integrated set of tools allows one to simulate tunnel construction and determine cost and times of construction, including uncertainties associated with geology and construction, which helps optimize the 3D alignment of the infrastructures."

Sousa, an expert in geotechnical engineering, is using ADSSC's STEP as a case study for her work. The MoU signed between Masdar Institute and ADSSC directly supports collaborative information and knowledge sharing about the project.

Nigeria launches first international conference

NIGERIA — Nigeria has joined the conference circuit with its first event to be held in Lagos on 29 and 30 March. The two-day event, the Tunnelling Association of Nigeria (TAN) Conference 2017 will feature the following speakers:

- Abidemi Agwor of the TAN committee, on the country's 10 year plan
- Tarcisio Celestino the ITA president, on the ITA, global trends and the role member nations have to play
- Olivier Vion the ITA executive secretary, on tunnelling applications for industrial development and how a local economy can benefit
- Imo Ekpo of the Large Dams Commission, on the potential benefits of underground space in Nigeria
- Otis Anyaeji the president of the Nigerian Society of Engineers

For more information please contact info@tunnellingnigeria.org

Bolanos completion

SPAIN — FCC Construction has completed the boring of the Bolaños tunnels (Verín-Ourense). The works entail the delivery of two parallel single-track tunnels, each 6.7 kilometres long, on the Madrid-Galicia High-Speed Line.

With an average excavation performance of 19.40 linear metres per day in the first tunnel, the work took 11.5 months to complete. The boring of the second tunnel saw an average excavation performance of 24.32 linear metres per day, resulting in a completion term of 9.5 months.

FCC Construction used an innovative solution in the construction of the tunnels. This involved the application of a stabilisation system for land of high geological instability. The excavation diameter is 9,900 mm and the useful cross-section 60.27 m².

The tunnel was lined using precast segments that are 370mm thick and 1,600mm long. The tunnel boring machine (TBM) used for the excavation was a single shield and manufactured by Herrenknecht in Schwanau, Germany.

TBMs unveiled for London Northern Line Extension project

GREAT BRITAIN — A joint venture of Ferrovial Agroman and Laing O'Rourke (FLO) has revealed the two tunnel boring machines to be used in the Northern Line Extension project under South London in the UK.

'Helen' and 'Amy', named after the first British astronaut in space, Helen Sharman, and British aviation pioneer Amy Johnson, are 6m in diameter and will start tunnelling from Battersea.

The 650t machines, each the length of a football pitch, will create two 3.2km underground tunnels (Helen will bore the southbound running tunnel to Kennington Park and Amy will bore the northbound tunnel to Kennington Green).

The project will extend the Charing Cross branch of the Northern line from Kennington to Battersea, via Nine Elms — helping regenerate the Vauxhall, Nine Elms and Battersea areas.

Two new stations are being also created at Battersea Power Station and Nine Elms.

The mayor of London, Sadiq Khan, said: "It's great news that we are going to begin tunnelling for the Northern Line Extension. Extending the line to Nine Elms and Battersea is going to be a real boost to south London, with the improved transport link helping to provide thousands of homes and jobs for Londoners. I'm also delighted that local schoolchildren have chosen two such inspirational British women as the names for these tunnelling machines."

David Darcy, project director of the Northern Line Extension, said: 'With our two TBMs now ceremonially named, in the tradition adopted across the tunnelling world, we will follow their progress in a 'personal' way. We will ensure that these two majestic 'ladies' are thoroughly cared for on their very important journeys. We wish Helen and Amy bon voyage!"

The Northern Line Extension, expected to cost up to £1.2bn, is supporting around 1,000 jobs, including 50 apprenticeships.

The project, the first major tube line extension since the Jubilee line in the 1990s, is due for completion in 2020.

See big picture article on page 16

WESTCONNEX PLAYS IT SAFE WITH DEDICATED PERSONNEL CRANES

AUSTRALIA — Five jib cranes supplied by Ranger have been deployed to the WestConnex road tunnel project in Sydney to facilitate man riding and evacuation. Originally the specification also covered general lifting requirements, however following discussions with the crane supplier it was decided to limit the use of the jibs to personnel movement.

Ashley Thacker, general manager at Ranger, said: "WestConnex needed a second point of evacuation from each of their shafts in the case of an emergency where workers needed to be stretchered out. The shafts range from 26m to 70m deep, hence the varying heights of lift. If the cranes were also used for goods lifting there was potential for rescue operations to be delayed, which is why it was suggested in consultation to limit their use."

The machines have a 1.5t working load limit, a 6.5m underslung height with 6m reach, and offer heights of lift ranging from 26 to 70m. Ranger chose 3t electric chain hoists from Swiss manufacturer GIS that were downgraded to 1.5t capacity to facilitate man riding. All were fitting with overload protection, a load cell with read out, pendant and remote controls.

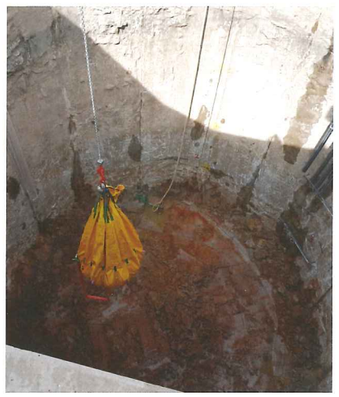
Thacker added: "Given the high profile nature of the site we only sourced from the best manufacturers in each component area. Even then, the hoists needed to be enhanced to comply with Australian standards for man-riding."

Challenges to the job included the lack of dedicated lifting points, which made lifting the columns from horizontal to vertical challenging and working near an open shaft, which presented safety concerns.

The cranes will be commissioned by the end of March and will remain onsite until project completion, scheduled for 2020. Regardless of what will be limited or zero duty, the cranes will be checked for full operation daily as a part of the site's pre-start requirements.

Upon successful installation, testing was carried out using water bags and training sessions with construction personnel were held.

***Below:** A jib crane is assembled on site, which was an unusual challenge and is then tested with water bags to simulate the load of a man rider*



SHELL CALLS FOR INDUSTRY INTEREST IN FUTURISTIC TECH

INTERNATIONAL — The head of research and development for Shell Bitumen has called on the tunnelling industry to look more closely at what materials technology can achieve. Professor John Read spoke to *Tunnels and Tunnelling* about a number of advances in bitumen technology prior to the turn of the millennium, but were not taken up due to a lack of interest in green technology.

The focus of governments has now changed, says Read, and it might be prudent to revisit what can be achieved by new road surfacing technologies. He highlights surfaces that can have a charge passed through them, causing them to attract PM10 particulates and clear a tunnel of harmful smoke, pollutants or dust more or less instantly.

Particulate matter 10 (PM10) is a major component of air pollution that threatens both our health and our environment. (PM10) pollution consists of very small liquid and solid particles floating in the air. Of greatest concern to public health are the particles small enough to be inhaled into the deepest parts of the lung. These particles are less than 10 microns in diameter - about 1/7th the thickness of a human hair - and are known as PM10.

Read and his team have also looked at surfaces that charge electric vehicles (for more on futuristic vehicles in a tunnel environment, see feature, page 37).

Shell recently announced that it is looking at what road surfaces might involve in the year 2050. "Global trends suggest that the world will continue to see continued population growth and rapid urbanisation, which as a consequence will see increased traffic volumes on road infrastructure," said a spokesperson. "At the same time,new, stricter emissions regulations will be implemented and new technologies will be more commonplace to power the world's vehicles."

Read added: "We are continually pushing the boundaries of bitumen. Today, from our global R&D centre in Bangalore, we have scientists working at a molecular level to make bitumen have the properties necessary to make more durable, sustainable and energy-efficient roads."

"Our investments in R&D are set to transform the humble highway into smart surfaces of the future. Some of these innovations will take a decade or more to come to the market, but others are already on-stream. Take Shell Bitufresh, which removes smell from bitumen, rather than simply masking it. This is done by chemically converting the mercaptans, the smell generating compounds within the bitumen, by attaching really heavy molecules from the Bitufresh to the mercaptans, making them incredibly heavy and dense, so that they sink to the bottom of the bitumen, preventing their release," said Read.

The company has requested tunnelling industry engagement: o.lim@shell.com

Below: An example of current technology: Mexphalte C was used for the pavements on the Stafelter and Grouft tunnel in Luxembourg, which is a low temperature synthetic binder

The MoD's only official photo of the operation

Britain sends tanks through Channel Tunnel

GREAT BRITAIN — The British Army conducted a test last month in which it sent five tanks to France through the Chunnel. The exercise was to see if the hardware could be deployed by rail in addition to sea and aerial routes. The test was low-key and few details are available, but it was successful and tanks can be sent by train to continental Europe.

The Ministry of Defence said that the test was "long-planned" suggesting that it was not a response to growing tension in Europe that has seen the biggest increase of Nato forces in Europe since the Cold War.

Kuthiran tunnel work to resume despite protests

INDIA — Work on the twin-tube Kuthiran road tunnel in southern India has resumed following protests, according to local media. The Indian high court had to issue an order to give police protection to the site after local residents disrupted works.

The locals were protesting blasting works, which they claimed were causing structural damage to their properties. As Tunnels and Tunnelling went to press, blasting had not resumed, although other site activities were ongoing. Some 75 local protestors had to be removed from the site before any work could resume.

The contractor carrying out the 1km drive, the Pragati Engineering and Rail Projects, had to deposit INR 30M (approximately USD 500,000) as advance compensation in case of future blasting resulted in any damages to local properties.

The company claims that it has also had to face costs of around USD 250,000 due to machinery being idle for a month. Construction originally began in the middle of December 2016.

Planning approval granted for Sydney Metro section

AUSTRALIA — Construction starts this year with planning approval received for Sydney Metro between Chatswood and Sydenham, including new twin rail tunnels under Sydney Harbour and through the CBD.

Stage 2 of Sydney Metro starts at Chatswood and travels beneath Sydney Harbour, through the CBD to Sydenham and on to Bankstown.

The approval is for the Chatswood to Sydenham section of the project.

Construction sites will be established in the Sydney CBD this year. By the end of 2018, the first of five tunnel boring machines will be in the ground carving out new twin tunnels.

Planning approval includes: Delivering 5.5km of new twin railway tunnels under Sydney Harbour and the Sydney CBD and seven new metro railway stations. Documentation is available online.

MORECAMBE BAY FEED NEARS COMPLETION

GREAT BRITAIN — Morgan Sindall's Professional Services and Underground Professional Services (UnPS) had nearly finished the Front End Engineering Design (FEED) for the Morecambe Bay cable tunnel project for National Grid as Tunnels and Tunnelling went to press.

The company said the 22km cable tunnel is one of the most challenging project of its type ever proposed. The tunnel will be 5m in diameter and will house two 400kV cable circuits to transport the electricity. Due to the strict ventilation requirements, and to ensure the high voltage (HV) cables do not overheat when fully loaded, an islet in the middle of the bay is proposed as a heat ventilation point and an emergency escape.

The tunnel is an integral part of the North West Coast Connection (NWCC), a plan to connect and export electricity generated by Moorside - a proposed 3.4 GW nuclear power station near Sellafield in west Cumbria. To minimise impact on the Lake District National Park, the power will be transmitted via a cable tunnel below Morecambe Bay's seabed, between Barrow in Furness and Heysham. The cable tunnel will enable the National Grid network to be fed from the power station's energy source.

Neil Lyons, National Grid senior project manager, says MSPS and UnPS demonstrated innovative capabilities, critical for this project: "This project requires various bespoke tunnel construction methodologies and linings designs, an understanding of marine works, and all the associated challenges from both HV cable installation and operational point of view, all with safety being at the forefront.

"The team has supported us from the outset, adapting designs with multiple options to satisfy different stakeholder groups, and completing the reference design within a very tight timeframe. We now look forward to their continuing support in our application for a DCO and in the subsequent invitations to tender."

Alwyn Hanekom, director of Power for MSPS, said: "Our initial appointment recognised our technical ability and innovative approach that challenges what the industry considers to be the norm. A project of this nature requires a significant level of multidiscipline experience, expertise and attention to detail, and will set the precedent for all future cable tunnel projects."

Professor Colin Eddie, managing director of UnPS, says: "We believe we have been able to add real value and influence to the process. Our rich heritage and industry-leading experience in major tunnelling projects has ensured our accomplished design engineers have provided the most realistic and buildable solution to our customer."

Awarded the contract in September 2015, and having now completed a significant portion of the reference design, the team is now supporting National Grid through a public consultation, after which the energy provider will apply for a Development Consent Order (DCO) prior inviting tender.

WHO GETS TO WORK

In the most recent issue of *Tunnels and Tunnelling North America*, **Nicole Robinson** used the Editor's Comment to explore the implications for infrastructure of the then-impending Trump presidency

Nicole Robinson
Editor of *Tunnels and Tunnelling North America*
Nicole is based in Minneapolis, Minnesota

Voters in the US, particularly rural, uneducated voters, have said their support for president elect Donald Trump comes not from a place of hate, misogyny, homophobia, Islamophobia, racism, nor a disdain of liberal elitism. Their support is for his plan to bring manufacturing back to US soil, to create more jobs through lifting moratoriums on pipelines and natural resource extraction projects, and by building infrastructure – be it roads, wastewater or the notorious wall with Mexico.

Allowing that a republican-led congress supports the president elect's USD 1tr infrastructure plan and it is implemented – which leadership has immediately stated it won't – infrastructure, construction and manufacturing jobs are not going to revive the rural US. Over the next 10 years the type of jobs people claim they wanted back by voting for Trump will be predominately in urban areas or outer-ring suburbs; they'll be in or near port cities.

The Trump presidency is laced with uncertainty. There are billions of dollars in construction work in the Northeast and Midwest to reduce combined sewer overflows. Particularly in Ohio and Indiana, cities of all sizes have mandates with the EPA—one of many institutions that newly-elected leaders have said they want to dismantle. That's not to say mandates are the only driving force in these cities' decisions to build new tunnels. Many are enthusiastically embracing the opportunity to clean up local waterways and improve quality of life. They may have pursued their projects regardless of federal intervention.

Undoing restrictions on fracking could improve job growth and boost the economy in various regions of the US. And Trump's drive to return more power to states could also increase local control over whether or not to implement more controversial fracking and mining projects.

Democrat leadership, including the current president and presidential nominee Hillary Clinton, has called for party members, supporters and everyone in the nation to unite and move forward. If the president elect is serious about his USD 1tr infrastructure plan, all democrats need to heed that call and reach out to the White House to make it happen. Come January, partisan politics should not hinder potential job growth under the new presidency.

At the very least, November 8 made it certain that Los Angeles and Seattle will provide opportunities for the construction, engineering and tunnelling industries for the next few decades.

The US is a divided nation and it's a confusing transition for many. In times of stress and uncertainty one of the best distractions is simply to get to work.

Much remains to be seen when it comes to the President's plans for infrastructure

Left: *A joint venture of Ferrovial Agroman and Laing O'Rourke (FLO) has revealed the two tunnel boring machines to be used in the Northern Line Extension project under South London in the UK. Read the full news story on page 8*

SEWER OVERFLOW

A study for "Developing a Conceptual Framework for Linking Sewer Condition Assessment and Groundwater Infiltration" was completed in the summer of 2016 and highlights some of the sewerage network's problems

Vania Goncalves
Vania is a staff reporter for the *World Construction Network* website

THE LATEST STUDY FROM the Centre for Research and Innovation for Groundwater Infiltration into Urban Infrastructure suggests that the issue of groundwater infiltration into sewers is a worldwide problem that can't be solved immediately.

Adam Cambridge, technical authority for urban stormwater management at Atkins – one of the Centre's partners – says: "We've completed a month's worth of literature review around it – not just looking at the work or research that has been completed in the UK but around the world. We found that the UK is not alone in this, everyone around the world is struggling with this problem of groundwater infiltration into sewers and no-one has got the answer when it comes to the degradation of the asset.

"It just emphasises the point that this is not a problem that can be solved immediately – it requires not only a PhD on it but will probably require several over a long period of time."

Forty per cent of the flow in the sewerage network is due to water seeping through the cracked pipes. According to Cambridge, the factors contributing to the deterioration of the sewer may vary depending on its location.

He says, "it's very difficult to go from a survey to a linear extrapolation across the whole system.

"We can't do one survey and expect it to be representative of all the locations, when there are so many other variables affecting the integrity of that sewer.

"Determining sewer factors is not linear – many factors can contribute. It is just not a case of surveying everything, but may be a case of developing new technology to monitor the performance and deterioration of that asset in time."

The Centre's first two years will be focused on groundwater infiltration into the sewerage network.

THE CENTRE

The Centre for Research and Innovation for Groundwater Infiltration into Urban Infrastructure was launched in 2015 by the British Geological Survey, Imperial College of London, Birmingham University, and Atkins.

*Above: **A group presentation as part of the study***

*Opposite and below: **Clear groundwater overflowing from a sewer onto the surrounding land***

It aims to tackle the economic and environmental impacts of groundwater infiltration on urban infrastructure in the UK, which costs tens of millions of pounds annually.

"For decades infiltration has been a long-standing infrastructure challenge for our industry," Cambridge says. "Local communities are often the ones most affected by the problem. This is the first time we've taken a coordinated approach to tackle the impacts of infiltration facing our infrastructure head on.

"Over the next five years, the Centre will bring together academics, researchers and industry to build an integrated approach in managing the environmental risk and economic impact to our sewerage network, hopefully freeing up capacity, reducing the overspills and saving millions of pounds in the process."

The Centre will be undertaking research with academia, researchers and industry to bring innovative and practicable outcomes, so that significant financial and environmental benefits can be achieved.

The Centre meets five or six times a year to discuss the different research outputs, says Cambridge.

"The role of Atkins at the Centre is to facilitate the bringing together of academic research and its applicability to the industry, and importantly to transfer the issues that we are facing in the industry back to academia."

He adds, "we are keen in making the best use of outputs in the projects we undertake but this is a long-term aspiration.

"This [issue] is not going to be solved in the next five or 19 years, and it is going to take a long time to actually see some progress."

Even though the solution for the groundwater infiltration into urban structures seems to be far away, Cambridge says that they are working towards one.

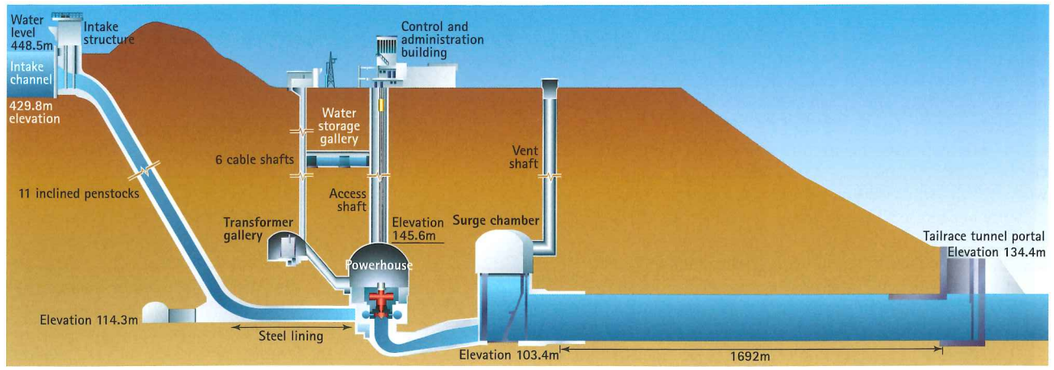
"There's going to be a heavy focus in understanding the problem first but the ultimate goal is to actually develop solutions, and some of these may be capital solutions, new bits of infrastructure, new bits of technology to monitor the performance of the asset, or new ways of developing business plans.

"We have the right people involved to progress with this problem and develop solutions"

This article was first published on the World Construction Network, a sister publication to Tunnels and Tunnelling: *www.worldconstructionnetwork.com*

A WORLD CLASS GIANT

As part of Canada's 150th anniversary in 2017 *T&T North America*, in conjunction with the Tunnelling Association of Canada, is celebrating industry's landmark underground projects. **Boro Lukajic** discussed the Churchill Falls Generating Station. Article reprinted here



Boro Lukajic
Hydro-power and tunnelling consultant, Mississauga Ontario, Canada

Acknowledgement

Special thanks to Gordon Hynes of Nalcor Corporation for approving this paper. Raymond Benson was responsible for rock mechanic design of underground cavities and tunnels. Andrew Merritt was responsible for construction aspects of underground structures.

THE CHURCHILL FALLS GENERATING Station is a hydroelectric power station located on the Churchill River in the heart of Labrador, Newfoundland. The underground power station can generate 5,428,500 kW, which makes it one of the outstanding engineering achievements of the 20th century, not only because it was the largest single underground hydro-electric power station in the world, at the time, but also because it was constructed in the remote wilderness interior of Labrador. It hosts 11 generators (rated at approximately 500 MW each). A controlled system of storage reservoirs 2,909 square miles (6,500 square kilometres in area) has been created by utilizing 39 miles (64km) of dykes, 88 in all, with more than half of these being classified as large dams using criteria of the International Commission on Large Dams. An average flow of 1,387 cubic meters per second (39,000 cubic feet per second), passes through 11 penstocks with a rated net head of 1,029ft (312m).

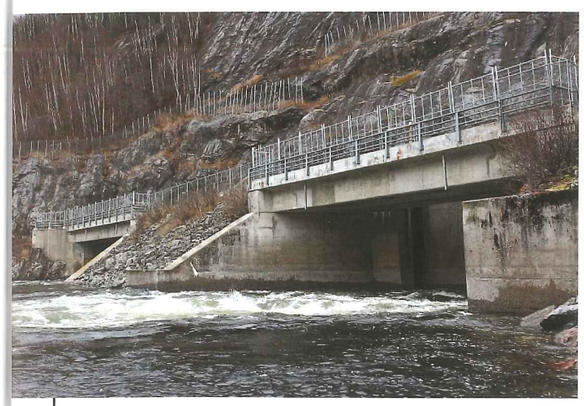
*Above: **The Churchill Falls Generating Station***

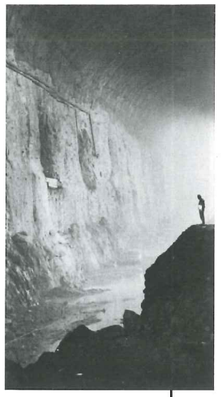
A great many people shared a vision that Churchill Falls would not only provide a world class source of hydro-electricity but the opportunity to bring other economic development activity to Newfoundland and Labrador. In response to the province's desire to see its largely untapped water and mineral resources developed, a group of banking and industrial firms established the British Newfoundland Corporation Limited in 1953. The generating station was fully commissioned in 1974.

The Acres Canadian Bechtel consortium acted as agents for CF(L)Co, charged with responsibility for engineering and construction management. The construction organization in the field had ultimate responsibility for contract administration, inspection and construction coordination. More than 180 construction and services contracts were awarded, ranging widely in value.

UNDERGROUND POWERHOUSE

The underground powerhouse 24m wide, 296m long and 47m high, was hollowed out of hard granitic rocks, close to 303m





beneath the Labrador plateau. Excavation of the main chamber began by driving the 33 x 28ft (10 x 8.5m) exploratory drift for the full length of the powerhouse. This was followed by using side slashes to expose the arch. The benching operation was done in a 35ft (10.5m) high benches using 6 x 6ft (1.8m) blast-hole pattern. Smooth-wall perimeter blasting was done along the walls. All blast holes were 2-in (50 mm) diameter drilled with 16ft (4.8m) steel.

INTAKE STRUCTURE AND PENSTOCKS

The 670ft (203m) long intake structure directs the flow from the lake into the penstocks. The rock pillars had to be sound and contoured to maintain the stability of the structure. Also, each intake had to be shaped to form a smooth transition between it and the respective penstock.

These objectives were attained by blasting each pillar and water intake in cascading lifts, using controlled blasting techniques to control overbreak and to minimize fracturing of the rock beyond excavation lines.

The penstocks are inclined at 58 degrees to the horizontal and spaced 71ft (21.5m) c/c at the intake. The diameter ranges from 22ft (6.6m) at the top, flaring in stages to 26ft (7.8m) near the bottom, before tapering to the horizontal section, which leads to the powerhouse.

Sinking of the 1,200ft (363m) long, 11 inclined penstocks was highlighted by imaginative use of new blasting technique and equipment. Churchill Constructors attained 250ft (75m) advance per week in each penstock, sinking two penstocks at a time. Key to this fast pace was the first use anywhere of two rail-mounted slashing jumbos.

The jumbo and the plate were suspended by separate cables from hoist houses located in the intake area. Each jumbo was equipped with six drills on hydraulic booms.

SURGE CHAMBER AND TUNNELS

Due to its large size, the surge chamber structure was excavated in three steps; first step included 33ft by 28ft (10m by 8.5m) pilot drift excavated to in the centre line at arch level; second step proceeded with opening the arch to full width by side slashes and the third step included benching with smooth-wall blasting along the walls. The chamber dimensions were as follows: length 232.56m, bottom width 12.19m, top width 19.5m, height 45.11m.

A 33ft (10m) diameter access tunnel (several kilometers long) was excavated with full face method.

Two tailrace tunnels, each 60ft (18.2m) high and 45ft (13.7m) wide, each 5,580ft (1,690m) long were excavated with a top-heading and bench method.

*Above left: **Churchill Falls tailrace tunnel portal 3***

*Above centre: **The facility today***

*Above right: **The powerhouse wall***

Typical cycle to excavate tailrace tunnels consisted of four hours drilling, five hours of loading explosives and five hours to muck out and vent; totalling 14 hours per mining cycle.

CONCLUSION

Harnessing the power of the Churchill River provided one of the greatest challenges ever faced by Canada's engineering and construction industries. The immense size of the Churchill Falls Development, its comparative isolation and tight construction schedule required imagination and innovation to overcome the problems encountered.

The skilful use of explosives, with credit to Canadian Industry Limited, combined with specialized equipment and experienced contractors, played a vital role in construction. The construction of this giant project, which made a significant contribution to Canada's economy, would not have been possible without an innovative and imaginative design provided by the engineers of Acres Consulting Services.

For almost a half century of operation, other than the regular maintenance, the continued stability and performance of the cavities has been exemplary. As an index parameter for rock quality designation, the RQD method was first used in Canada on this project

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CROSSRAIL'S DRILLING RIG

Crossrail is using a bespoke automated drilling rig for boring service connection holes, and fit out contractor ATC says that the investment has already paid off

Below: The rig was designed and built by Rowa

Bernadette Ballantyne
Bernadette is an engineer and freelance technical journalist

WHEN CROSSRAIL COMPLETED ITS epic tunnel boring efforts in June 2015 it took the project from one major stage of construction to another. With the two 21km, twin tube, 6.2m diameter tunnels in place the Alstom, TSO and Costain (ATC) joint venture could push ahead with its challenging GBP 300M (USD 376M)

Designing the rig

One piece of work, explains Rowa's Alberto Belloli, was to bring everyone together within the joint venture and the design team of Crossrail and eventually freeze their needs to be able to say "this is the final position of those fixing and this is the number of combinations that you could be confronted with".

The second big topic was then to ensure the data flow starting from the digital model of the finished tunnel lining. "You leave the comfort zone where you have an ideal model and can assume at any point that you will be at the right point to drill now you get confronted with reality and have to fit that into your model." The team are matching their needs with the digital model of the tunnel and coming up with updated drilling files.

Defining the syntax was the third area. This is the formal aspect of that information so that the machine could handle that and also took a number of weeks. The software is quite complex and the original concept was to have a global station with an operator following the machine on site telling the machine how to align itself. A decision was taken jointly with ATC and Rowa to reject the idea to have that global station and operator on site every day for 10 hours a day and have something based on the input data, with the rig aligning itself automatically after every repositioning.

"Fourth we had to consider the dual mode of operation. Enabling the machine to run on rails and road and cope with inclines of 4 per cent." Finally a key challenge was finding a way to have a fairly sophisticated piece of equipment that can cope with all of the requirements, provide all that information for example track back whether a hole has been drilled or not. At the same time we are still in a tunnelling environment and need simple intuitive way of operation and clear instruction. This makes it a big challenge to find a machine that is a true innovation, which pushes the boundary of what is feasible further. At the same time it has to be robust and suitable for the harsh environment in tunnels.

fit out contract. But in order to fit the services including overhead power lines, the cable management system, emergency walkways, firefighting system and electrical cables, ATC needed to drill a lot of holes - more than 250,000 to be precise. And in typical Crossrail style the contractor looked for new, more efficient technologies to accelerate the process, resulting in the creation of a bespoke automated tunnel drilling machine.

"When you do this manually you need two teams. One that goes ahead and marks out where the holes go and another actually drilling them and putting the brackets in, so with this we have eliminated a whole team of people," explains Tim Kelly, lead engineer at ATC for the automated tunnel drilling machine. "And it is not just about the people. This is a much more streamlined process. It consolidates the surveying activity into the drilling activity and from a health and safety perspective the risk is as low as reasonably practicable."

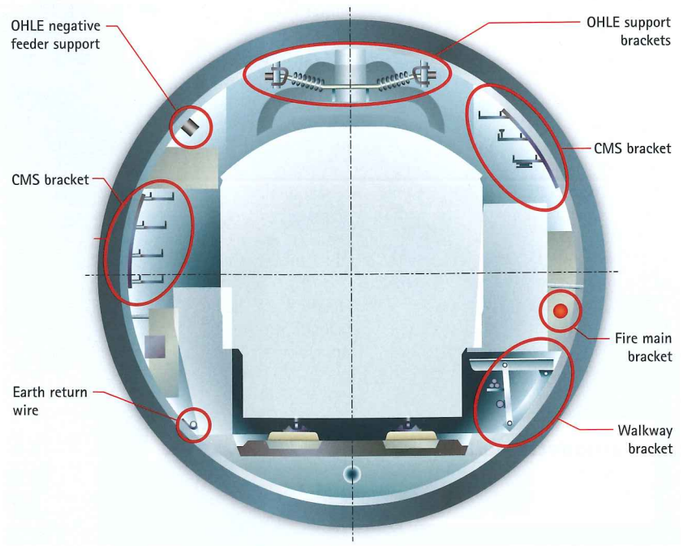
Manufactured by Switzerland's Rowa with drills from Hilti, the automated drilling rig has sophisticated software that allows it to read the data that tells its hydraulically operated arms where to place the drill holes. Operators can check this on the control panel. This data originates from a 3D scan of the tunnel taken a couple of weeks before the rig is scheduled to drill each section. "From that scan they take out key locations on the tunnel in a coordinate system and we take that data and convert that with a computer programme into the drilling locations. That data is then collated and checked before it is inputted into the machine so that it knows where it needs to go," explains Kelly.

When the machine is ready to start drilling, targets are placed onto the reference points on the tunnel and the rig uses laser guidance to determine its position, using the tunnels centre line and a guide roller either side of the rig as equalisation points. "Once you have done that the system is automated, it sets the arms, it rotates up or down to the correct angle, it sets a reference point for the drill and it drills 135mm or 150mm whatever it is set to on every hole," he says.

Each rig, and there are two on the project, has four operators and a traffic light system is in use to ensure that drilling takes place exactly where it is supposed to. A red light indicates that the drill is more than 250mm away from the target and amber and green indicate that it is closer or on target.

"In the best case scenario for rig one, which drills more holes, we target at 250m/d and we generally achieve 200-250," says Jonathan Cox, M&E tunnels team leader for ATC. "The factors that stop it achieving that might be how far the guys have to walk to get to it and if they are coming in on a train and there

*Below: **Cross section of the tunnel showing various brackets***



are knock on effects from other activities or if it is on a steep cant where the inclination and curvature of the tunnel are at a maximum then it is harder for the machine to find its alignment – it finds it but it takes more time," he says.

Rig one is responsible for installing holes along the sides of the tunnel, typically around 16. A second rig is responsible for drilling the holes for installation of overhead lines, which sit vertically above the tunnel along the crown.

*Above: **Two Rowa rigs were used to drill the array of more than 250,000 holes required for services on the project***

DUAL MODE

For most of the project the rigs have run along the rails of the Crossrail tunnels but it also has another operating mode giving it more flexibility. "The machine can run on tyres and rail. It is a very clever piece of kit," says Gregg Purcell, railway systems construction manager for Crossrail. "It is totally flexible. It is a lot easier on the track, on the rubbers it is a slightly harder configuration to work with."

Slightly harder because driving it along the road makes it more difficult in terms of maintaining alignment meaning that average progress here was around 200m/d rather than 250m/d. But the team maintain that this option was vital in terms of maintaining productivity. "It was a big benefit to the programme because we were able to get in and put brackets on before the concrete train and all the sleepers and everything came in so we did some quite good acceleration of the programme by coming in from the Pudding Mill Lane branch down to Stepney in the eastbound [tunnel] with the drilling rig," says Cox.

For manufacturer Rowa these operational requirements were not easy to accomplish. To be dual mode the axles had to be much wider than those of a track mounted machine and the underlying steel structure had to be analysed to ensure that it could withstand the induced stresses.

At the same time the tunnels are not perfectly flat. "The difficult part is that Crossrail has a critical inclination of 4 per cent that we had to take into account for dimensioning," explains Alberto Belloli, managing director of Rowa. "In the end it was a matter of selecting the proper drive solution. We ended up with hydraulic drives and we had both axles equipped with a drive and brakes.

"You could say that we doubled the installation or installed breaking power and drive compared to the requirements so that if one of those systems breaks down you still have the other one and you can work in a reduced mode or at least safely shut down the machine without losing control."

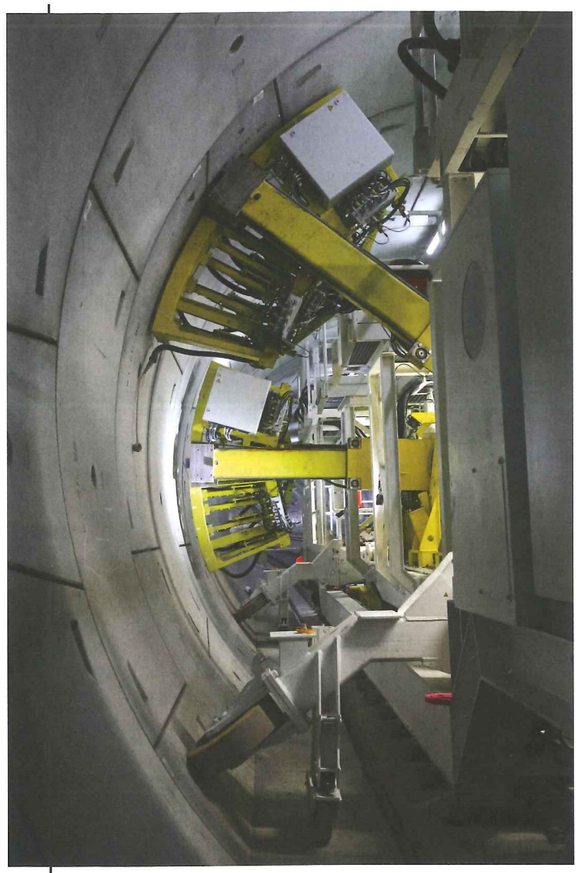
DUST STRATEGY

Another key challenge for the contractor has been related to the drill bits and dust removal strategy. "Hilti came up with a really innovative solution, which was represented by hollow drill bits and then a vacuum connected to the drill bit with an adaptor sucking out the dust directly within the hole, which is of course the optimum solution for leaving a clean hole behind and reducing wear," says Belloli.

However as drilling got underway it became apparent that a change of strategy was required. "The segments had steel fibres in them so what was happening was they were wearing the hollow drill bits down very quickly and it didn't become cost effective to go ahead with this solution," says Rick Flora, manager for Hilti UK. "So what we did was provide them with high end drill bits [the TE-CX carbide bits] and then designed a new bespoke dust extraction system for them to go with the equipment that they already had."

This was carried out in just four weeks at Hilti's Kaufering facility at a cost of around EUR 100,000 (108,000). "Priority number one was to come up with another bespoke solution for the dust. This was the first time that we have ever made something outside of our portfolio and to turn it around in four weeks was pretty good going," says Flora. "We had a good relationship with ATC and Rowa so that helped a lot. We swallowed 100 per cent of the cost, we didn't cross charge anyone for this. It was very important to do, because of the nature of the project."

*Below: **The machine was bespoke for the Crossrail project***



The solution was successful and by December the team had drilled 25km of tunnels and according to ATC justified its worth as an investment. The progress record so far sits at 800m achieved over a weekend. "I'd say as a start-up machine developed for this purpose it has gone very successfully.

"We don't have major issues with the procedure or how it operates, it is just little issues and bugs that we are trying to iron out occasionally as the operation moves forward," says Kelly.

One of the "little bugs" is the occasional need to double check the data files or ask for software support from Rowa in Switzerland.

"The guys on the rig are very capable operators who come from a plant background but quite often it is to do with the dataset that is prepared. That data is prepared by a programmer who is a sub-contractor to ATC," says Cox, noting that this means that the sub-contractor is not always working according to the same cycles as the drill team, which is something that Cox would do differently on future projects.

"I'd make sure that the guy writing the programming would be onsite all the time and there would be more responsibility on them. You could still have supply of the machine separately but the operation and supply of the data I'd try to tie those contracts together so that there weren't people waiting for someone else who isn't part of the same cycle."

Another issue that the team must contend with is a clash between placement of platform screen doors and the rig. Once the doors are installed the rig cannot be moved past them as they reduce the tunnel diameter. "We'd like to do the rest of the tunnels with the rig but as more of the screen doors go in we get limited in our exit points and it is likely that we will do another 8 or 9km with the rigs," says Kelly.

FUTURE POTENTIAL

With this being the first time a rig like this has been used in the UK there are naturally some operational lessons that the team has learned from the experience. "When we specified the machine there was a lot more space in the programme, where there wasn't something trying to work in front of the drill rig, but now the programme is more congested," says Cox. This means that other work vehicles such as the concrete train might need to pass the drill rig on a daily basis and so the drill team have to move the rig in and out losing valuable time. "Wherever we can we leave it parked in the tunnel and the next crew come and start exactly where it left off."

By leaving the arms folded down in the deployed configuration the drill team ensure there is no loss of start-up time. But this became compromised by the need for other rail operations meaning that the machine had to be closed down and driven in and out. "We did look at trying to make the braking system compatible with a loco [motive] so that it could be towed in and out but it was too late as the brakes were not compatible. That would be a change we would recommend for future drilling machines – to be sure you can move it quickly in and out," says Cox.

*Above: **Crews rated the performance of the machine very highly***

*Right: **Record progress was 800m over a single weekend***

Belloli says that this is something that could be changed for future rigs. "If we were to develop the equipment once again, there certainly are a number of features we could design in a slightly different manner. Among these, the capability of folding and unfolding the machine in shorter time and a higher travel speed for the self-propelled mode. This would respond even better to the changed requirements of the contractor, and address aspects regarded as marginal while specifying the requirements, which however turned out to be relevant during operation."

BIG MOVE

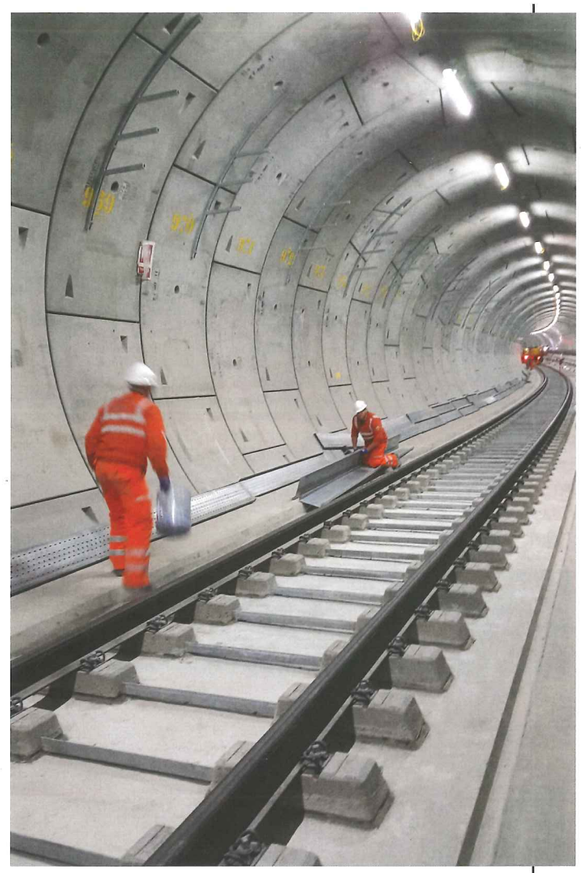
By far the biggest move that the machine has had to undertake is moving it from the factory in Switzerland to the Crossrail project in London. Despite the well-planned operation there were a few challenges to overcome. "Originally we planned to disassemble the rigs in parts, which had to be as big as possible so that you didn't have a lot of time to reassemble," says Belloli. But due to time constraints and the limitations on site in terms of facilities, lifting devices and expertise it was decided to transport it in one piece. With a total weight of just under 40t, that one piece was heavier than the initial estimate.

"If you are heavier than expected you need to integrate your trailer with additional axles and this is the easy part," says Belloli. "There is then the bureaucratic part. A heavier truck needs new permissions and the paperwork can be quite time consuming."

At the same time Paris was hit by a series of terror attacks in mid-November 2015 meaning that border forces had other priorities to deal with. Despite this Crossrail had its rig within 10 days. "I think it paid off because everything we considered and fixed at the workshop was still intact when it came onsite. I would adopt the same approach again, fixing everything at the workshop and moving it in one piece and then organise the transportation the same way as Crossrail."

But Belloli points out that this might not be possible depending on the dimensions of the tunnel using the rig.

Looking ahead all parties see the potential for automated drilling on future projects. "For productivity, health and safety, the quality of the work, quality control, whenever the size of the project allows it should be the method of choice," says Belloli. "Within the metro size works we could even image a piece of equipment which is reusable."



*Both: **Work to fit brackets to the tunnel lining***

"We have expectations that it will be used again in the future," agrees Flora pointing to projects in France, Dubai and Denmark. And Rowa too says it has had requests from continental Europe, Australia and Hong Kong.

However the ATC team point out that prefabricating the segments with the drilled holes included would be a more efficient option once on site if challenges around positional issues and the cost of doing this can be mitigated.

"I think that in the situation that we were in where there was nothing cast in to the segments then it is the way to go," says Cox. "But if you look at a project holistically casting some dowels or receiver sockets or something of that nature into the sockets means that you don't need to drill any holes"

MILAN TO GENOA HIGH SPEED RAIL

Paola De Pascali visited the sites of the Terzo Valico dei Giovi project, the new high-speed Milan-Genoa railway line

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

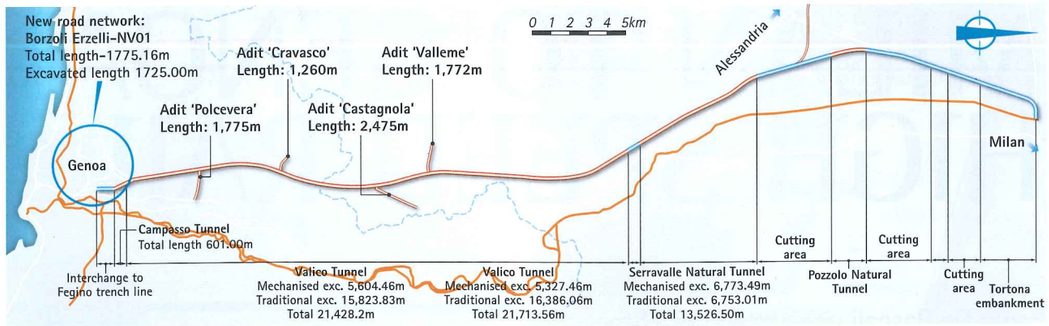
THE MILAN-GENOA RAILWAY line, also known as Terzo Valico dei Giovi, is one of 30 European priority projects. It links the port of Genoa with Milan and Turin in Italy up to Rotterdam/Antwerp through Switzerland. Started in April 2012, the project is about 53km long and involves the construction of two single-track, parallel tunnels with a total length of 37km, connected by cross-passages every 500m.

The general contractor is the COCIV consortium comprising Salini-Impregilo (64 per cent), Società Italiana Condotte d'Acqua (31 per cent) and CIV (5 per cent).

Above: The line is part of the European rail network linking Genoa and Rotterdam

Milan-based engineering company Rocksoil is the COCIV's design consultant for underground works and is responsible for job site technical assistance.

The Interministerial Committee for Economic Planning (CIPE) approved the final project in April 2006. In 2011 COCIV and RFI – the owner of Italy's railway network - signed the contract for detailed engineering design, construction and



construction management. The project cost is EUR 6.6bn (USD 7.1bn) and is funded by RFI.

According to the contract, 60 per cent of the civil and permanent works have to be performed by third-party companies chosen by means of international tenders. This is for risk reduction reasons. The project is scheduled to be completed by the end of 2021.

BRIDGE BETWEEN SEAS

The high-speed line will work as a "bridge between two seas," connecting the port of Genoa with Rotterdam via a 200-250km/h rail link. The new line focuses on sustainable transport modes, transferring large amounts of freight traffic from road to rail, with benefits for environmental, safety and social issues.

The 53km-long Terzo Valico tunnels are located in the complex Apennines range between Piedmont and Liguria. The new line is connected to the existing line:

- to the north side to Milan through the existing line at Tortona;
- to the north side to Turin through the Novi Ligure Shunt that connects to the new line with the existing Genoa-Turin line;
- to the south side to Genoa and to the Port of Genoa through "Bivio Fegino";
- to the south side to Voltri and the Port of Savona through the interconnection of Voltri.

Starting at the Genoa hub, the new line will run along the Genoa-Milan route, as far as Tortona, and along the Alessandria-Turin route, and will then connect with the existing lines in Milan and Turin.

In terms of tunnel construction, the main works include: Campasso Tunnel of 716m (single-tube, dual-track); two Voltri Interconnecting Tunnels of 2,000m and 2,5000m (both single-tube, single-track); Valico Tunnel of 27,110m (dual-tube, single-track); Serravalle Tunnel of 7,094m (dual-tube, single-track); access adits of 7,200m; and a tunnel made from precast segmental rings for 8,000m. Four intermediate access adits (Polcevera, Cravasco, Castagnola and Vallemme) are required for the Valico Tunnel, both for construction and safety purposes. From the Serravalle Tunnel's exit, the main line is mainly above ground or in an segmentally lined tunnel, until it joins the existing line in Tortona (en route to Milan), while a diverging branch line establishes the underground connection to and from Turin on the existing Genoa-Turin line.

*Above: **Figure 1, The various sections making up the project***

COCIV director Pierpaolo Tommasini explained that the name "Terzo Valico" is refers to it being the third span and references the existing lines.

"The first line, the Passo dei Giovi, was built around 1850, followed by its branch, the Succursale dei Giovi, with smaller

*Below: **Figure 2, The full corridor for the link between Rotterdam and Genoa***

inclines and larger radius of curvatures than the previous line," Tommasini says.

"We are currently working on the third line, which features a limited incline and really large radius of curvature to allow the transport of goods by train according to the more modern European standards."

WORK IN PROGRESS

Tommasini talks about the construction progress, starting from the northern entrance of Serravalle tunnel.

"Excavation work for the segmentally-lined tunnel section is ongoing, which is through alluvial formations near the Scrivia stream's plain and its tributaries," he says.

"We have already completed two of the adits, with the remaining two by March 2017. Now we are ready to start digging four faces of the Valico Tunnel."

Near the southern entrance, excavation of the 30km base tunnel has begun.

"We have already completed the Campasso tunnel, which is located shortly after Giovi's branch," Tommasini says. The tunnel is 608m long with double tracks up to the Valico tunnel and then two single tracks with cross-passages.

During *T&T*'s visit to the intersection tunnel between Voltri and Valico inside the GN 13 chamber, Rocksoil's geologist, Ilario Larosa, showed that each tunnel is equipped with formwork for inverted arches and sidings (kickers). "Before spraying concrete we need to waterproof the cavity to prevent any damage to the groundwater," Larosa says. "It's also important to analyse the face, to determine how best to advance.

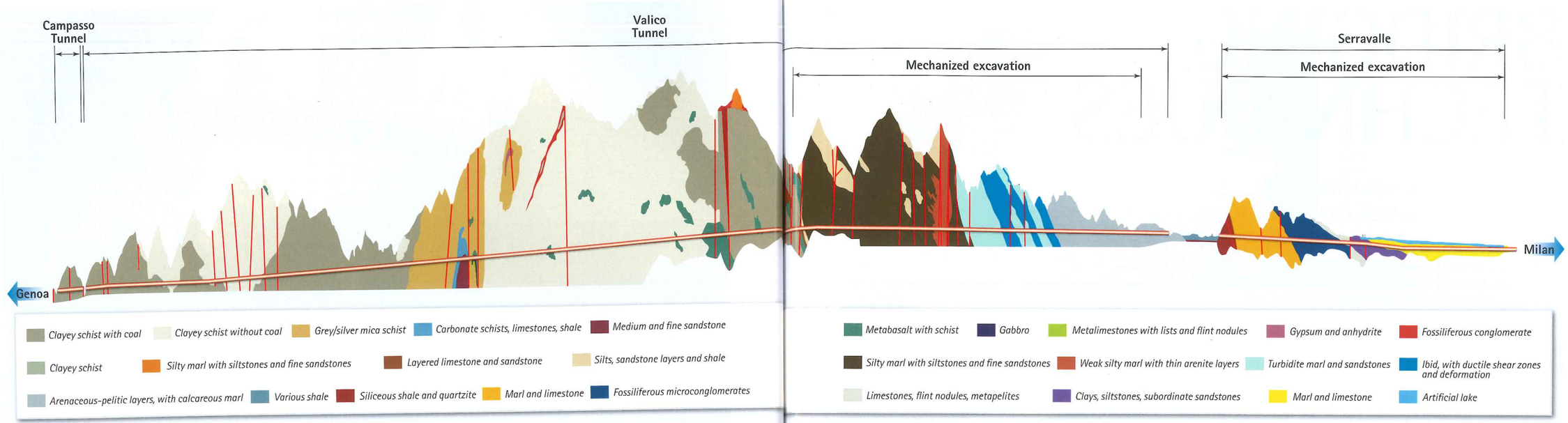
"When the face suggests good geological conditions and minimal deformation there is no need to reinforce it. If the face evidences particularly strong material, we can proceed quickly and safely using non mechanised excavation. When the rock is highly deformed and the face shows significant extrusion, we insert fibreglass tubes to reinforce and stabilise the core ahead of the advancing tunnel. After excavation the fibreglass tubes can be dumped with the rest of the spoil. Spoil on this project is used in the environmental restoration of abandoned quarries."

*Above: **Formwork in use on the project***

SAFETY MEASURES

In an emergency, train passengers will be evacuated to a safe area inside the Valico

*Below: **View of a tunnel portal***



Above: Figure 3, A geological profile of the tunnel length

tunnel, near one of the adits, called the 'Lemme Valley' adit.

According to the safety plan, two pedestrian tunnels will be ready to receive evacuees. The tunnels are 750m-long and are both linked via a "transect" that overpasses these tracks, reaching the adit, which works as an emergency exit and vehicle access point.

This flyover also connects two nearby platforms with the two evacuation tunnels. Passengers can either escape to the clear tunnel and then board another train or go to the emergency exit at the Lemme Valley adit. A vehicular tunnel will also be built to connect the adit with the down track evacuation tunnel.

The safety facilities include emergency escape lighting along the tunnels and, a surveillance system in addition to the fire suppression and smoke control system.

The safety plan also involves the presence of emergency vehicles on the new line. They will be equipped with special devices to safeguard passengers.

Below: View from a waterproofed section of tunnel towards the face

GEOLOGICAL CONDITIONS

The final design of the Terzo Valico project required a geological survey to analyse the complexity of the Apennine ground. This cost EUR 84M (USD 90M) – 2 per cent of the total cost of the project. The survey revealed different types of ground ranging from clayey schists to limestone, argillites and even loose soil, sometimes with extensive water content.

Overburdens reached 600m. During the survey the route was divided into sections with similar geological and geomechanical features.

It was also discovered that 30 per cent of the Valico Tunnel crosses an area with exceptional geological complexity. This is the Sestri Voltaggio area, which has an overburden of 600m and consists of a sub-vertical surface, roughly oriented from north to south. According to the most recent interpretations, this area is "a channel of preferential concentration of the tectonic deformation".

Some formations also show gas and occurrence of asbestos. "To prevent any fire or explosion risks, appropriate ventilation and the use of explosion-proof equipment was required for sensitive areas such as the Lemme Valley," Tommasini says.

The rock samples collected during geotechnical investigation were analysed by the Institute of Environmental Geology and Geoengineering (CNR) at the Polytechnic of Turin.

The final study says: "In general the amount of asbestos minerals was modest. The specific procedure for determining the hazard in regard to the release of fibres has highlighted their harmlessness."

EXCAVATION METHODS

Both non-mechanised and mechanised excavation will be used for the Terzo Valico tunnels. The 7,000m Serravalle Tunnel will be completed entirely with TBM excavation, using two 9.73m-diameter Herrenknecht EPBMs. Conversely, the Valico Tunnel will be excavated using both technologies: non-mechanised from the southern entrances and from the four access adits, and mechanised excavation, using two 9.77m-diameter Herrenknecht EPBMs, from the northern entrances.

The excavated diameters of the tunnels and the access adits, completed using non mechanised excavation, are approximately 9m. Rocksoil project manager Andrea Bellocchio says that excavation was advanced full-face at all times, even under the most difficult stress-strain conditions, after reinforcing the core-face with suitable stabilisation tools.

Reinforcing the core face with suitable technologies (fibreglass structural elements, horizontal jet-grouting, mechanical pre-cutting), it's possible to control ground extrusion during the excavation. It is important to have the invert and kickers close to the excavation face, particularly in difficult conditions.

As *Tunnels and Tunnelling* goes to print approximately 10,000m of main tunnels and adits have been excavated. Also the large intersection chamber (GN13, cross-section 400sqm) at the southern entrance of the Valico Tunnel is almost completed. The average rates of advancement have been in the order of 40m/month/face for non-mechanised excavation in full-face, reflecting the degree of stabilisation required, whereas the average advance rates for the mechanised excavation have been around the 165m mark per month, with peaks of up to 300m per month.

LOGISTICS AND SITE PREPARATION

The tunnel entrances and adits have been positioned near disused industrial lands to avoid impacts on the environment.

Site preparation for the entire project includes: the construction of base camps and villages to accommodate personnel; the construction of new roads and the adjustment of the existing ones for the trucks; the construction of operational sites; concrete mixing facilities; equipment for the excavation and construction of the tunnels; installations to build the railway superstructure (ballast and tracks); installations for the construction of railway technological systems; installations for the crushing and production of the aggregates needed for the concrete; extraction sites for quarrying the aggregates needed for carrying out the earthworks or for concrete; mitigation of environmental impacts that are inevitably created with construction sites as extensive and complex as those necessary to complete this project

Below: 'Conventional excavation' in progress, defined by the ITA as anything non-mechanised

BRIDGING TECHNIQUES

Adaptation of bridge replacement technology into the tunnelling sector has been implemented for two projects

RAPID BRIDGE REPLACEMENT IS a construction technique that has been gaining momentum in recent years. In seeking to reduce the time that critical roads are out of action, municipalities and highway operators have been maximising off-site construction. For bridges this means building the new structure and installing it as a unit, rather than building it in-situ.

Moving bridges has been made possible thanks in part to development of self-propelled modular transporters (SPMTs). These lifting devices carry huge loads along a series of axle lines that can be adjusted depending on the size and weight of the required load. Each transporter consists of anything between four and eight axle lines along with its own power and control systems. But crucially the units can be stacked together both longitudinally and horizontally to create a transportation system suitable for loads of any size or shape.

Lifting two tunnels of up to 3,600t in Warsaw then, was a straightforward task for Mammoet's SPMTs. The firm was brought in by Austrian contractor Strabag to develop a new solution for installing tunnels beneath a railway in the city centre. "Warsaw Municipal Road Building Project Authority as a developer wanted to connect the city centre and the Targówek district in Warsaw," explains Adam Malik, project engineer for Strabag. "The contract where the tunnels were built is a section of Świętokrzyska route, with its length about 3km."

But to provide the connection to the Targówek district meant tunnelling underneath the existing live railway and the client did not want to undertake a lengthy possession that could have meant closing the railway lines for months. "The original idea

Bernadette Ballantyne
Bernadette is an engineer and freelance technical journalist

was to close it and somehow redirect all those lines to other railway roads but this would be very difficult," explains Edvinas Ivanauskas, general manager of Mammoet Baltic. What is more the rail lines were not only for local connections but international trains. "We partnered up with Strabag and they asked us to look at the problem in a different way. They said you have to do it in a couple of days and all in all we have a week or two maximum closure of the railway," he says.

Mammoet therefore came back with a solution based on constructing the two required tunnels as independent structures close to the final location and then moving them into place. "As the first structure was 3,600t we could do it in a couple of ways, we can do it in a skidding way where you put it on a big railway track then push it with special hydraulic systems, or we can put on multi-wheeler SPMT and we can drive it and position it to 10mm precision," he says.

Due to the ground conditions, which included a high water table, and restricted city centre area it was decided that skidding would be too time consuming and require too much ground preparation work to undertake. The SPMTs would be faster. "Using our method to pick up from the original place and drive it to the final point took us around an hour and a half. That makes a very big difference," says Ivanauskas.

But before work could start on site Strabag had to be convinced that this new method was worth the investment. "The client asked us to make a test so they could see it because they have never built it before so we asked them to come and see a big structure that we were driving around in Holland. For them and for us everything was working as planned and this convinced the client to take a new approach," he says explaining that this itself was a huge achievement as it required a completely new way of thinking.

Following the test, the client decided to move ahead with the new approach. "This Mammoet technology in comparison to other options enabled us to reduce temporary works like sheet pile walls, temporary viaducts, and temporary concrete slabs. Reducing impediments into railway traffic was also very important to get acceptance by the railway authority," says Strabag's Malik.

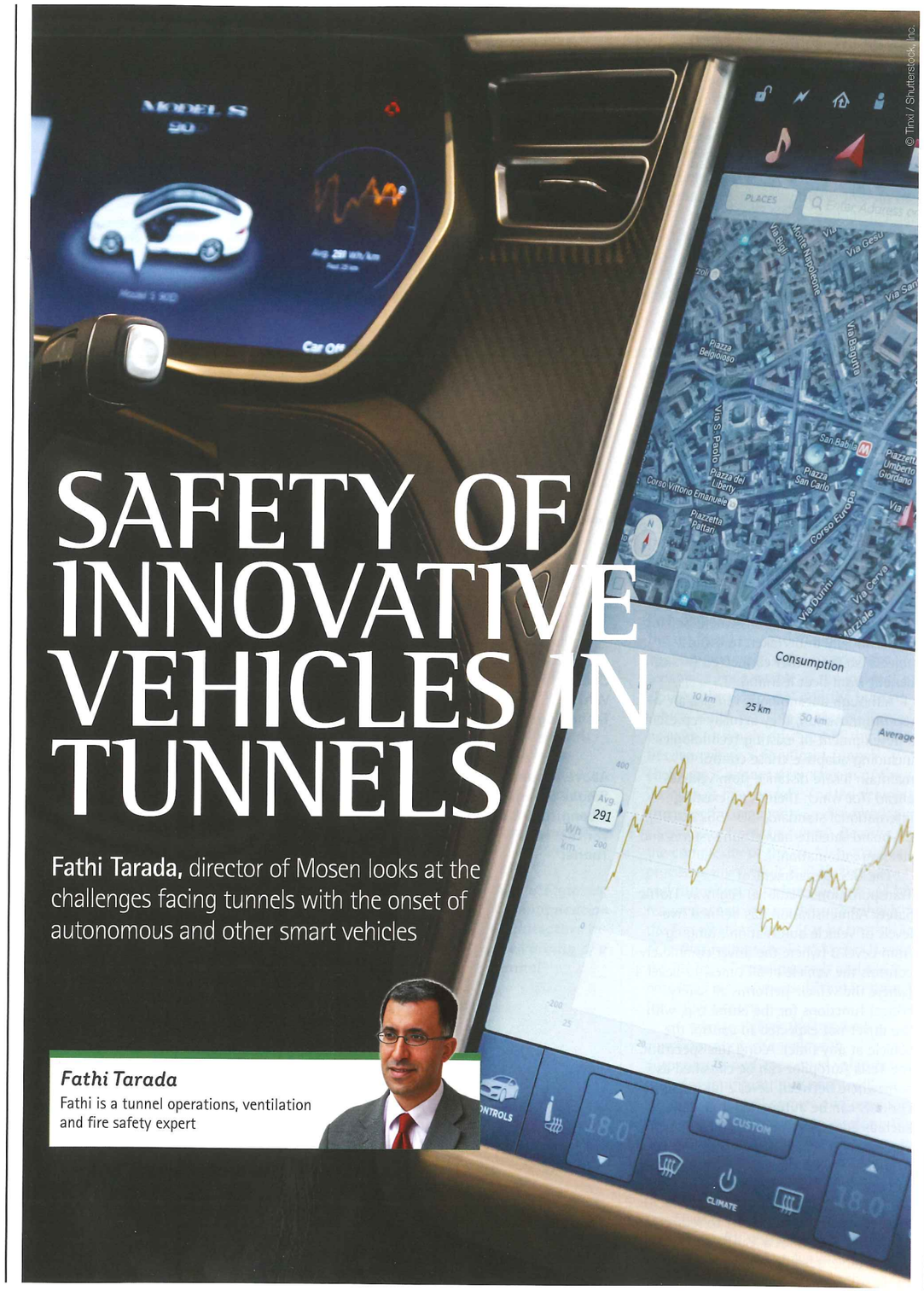
Explaining that the ground itself was strong and cohesive Ivanauskas says that the preparation for the tunnel insertion was simply to excavate the hole beneath the railway and install a concrete support framework for the tunnel to sit on. "There was no special preparation required. It was built on special supports which we could drive under."

The tunnel sections were sitting on a prefabricated base which held the tunnel up at a level which allowed the SPMT to drive beneath it. Hydraulic jacks were then used to lift the tunnel from the base before the SPMT drove it over to the new location. The SPMTs were operated using remote controls. "The tunnel was not straight and we had to position the whole thing a couple of degrees," says Ivanauskas. "We did this move and positioned it exactly, for the client they had never seen that."

Careful consideration had to be given to the structural integrity of the concrete which was at risk of cracking. "We also had to be very careful with this. It is easy to crack concrete, steel has much different bending moment to concrete. It can crack quickly so there are big engineering calculations needed for this," Ivanauskas says.

The first, and largest of the two tunnels was installed in June 2016. This tunnel was 80m long and 9m high. The second 3,200t, 70m long tunnel was installed a few months later in September. Constructing each tunnel took a number of days rather than months. For example, the second installation from excavation to installation to backfilling and reopening the railway took a total of 18 days and the client says the method proved very useful. "Technology to transport civil engineering constructions with SPMT trailers appears as a very useful method to minimalise impediments into the public traffic and gives opportunity to reduce time and costs of works," says Malik

Tunnels and Tunnelling is aware that readers will likely have unanswered questions relating to this interesting project. However, more information was not forthcoming despite efforts.



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SAFETY OF INNOVATIVE VEHICLES IN TUNNELS

Fathi Tarada, director of Mosen looks at the challenges facing tunnels with the onset of autonomous and other smart vehicles

Fathi Tarada
Fathi is a tunnel operations, ventilation and fire safety expert

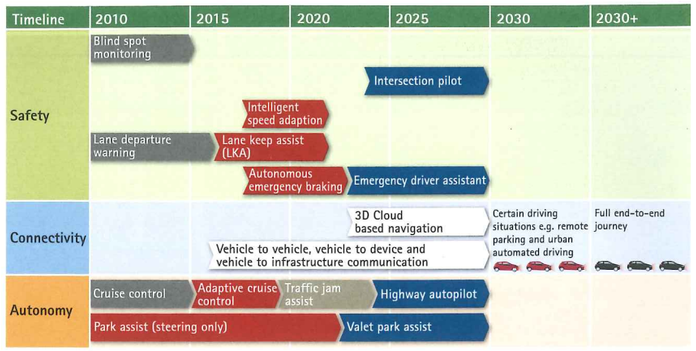
VEHICLE TECHNOLOGY IS EVOLVING quickly, with autonomous cars now a reality, and with an increasing proportion of hybrid and electric vehicles on the road. Such innovation can bring many advantages in the management of traffic flow and the reduction of emissions. However, innovative vehicles can present significant risks to road users, particularly in tunnels. A good understanding of the sources of these risks, and how to mitigate them is essential for manufacturers, designers, tunnel owners and operators, as well as for the fire service.

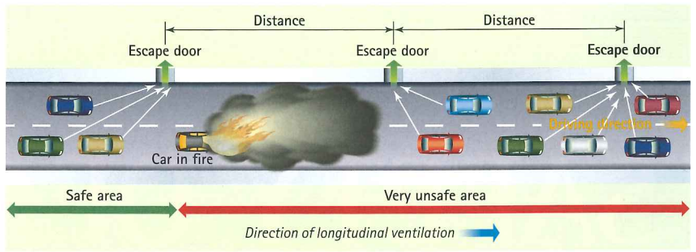
AUTONOMOUS AND CONNECTED VEHICLES

Autonomous vehicles such as those driven by the Tesla Autopilot can sense their environment and navigate without human input, at least in certain traffic conditions and within specific time periods (Figure 1, page 37). They achieve that by using a combination of cameras, radar, ultrasonic sensors and other data to automatically steer along the road, change lanes, brake and adjust speed in response to traffic. Such autonomous vehicles can be connected to the data cloud, uploading locations where braking was manually undertaken to avoid objects, so that other connected cars can benefit from fleet learning.

Although autonomous vehicles are a recent innovation, they actually represent a development of existing technologies including adaptive cruise control to maintain a safe distance from vehicles ahead (for which there is an existing international standard, ISO 15622:2010), on-board satellite navigation systems and steering automation.

The U.S. Department of Transportation's National Highway Traffic Safety Administration has defined five levels of vehicle automation[1], ranging from Level 0 (where the driver completely controls the vehicle at all times) to Level 4 (where the vehicle performs all safety-critical functions for the entire trip, with the driver not expected to control the vehicle at any time). Along this spectrum, the Tesla Autopilot can be classified as somewhere between Level 2 (at least two controls can be automated in unison, such as adaptive cruise control in combination with lane keeping) and Level 3 (the driver can fully cede control of all safety-critical functions in certain conditions; the car senses when conditions require the driver to retake control and provides a "sufficiently comfortable transition time" for the driver to do so). KPMG predicts that the evolution of current technologies will enable full vehicle autonomy to be realised by 2030 (Figure 3).





*Top: **Figure 2, Evolution of Autonomous and Connected Vehicle Technologies[2]***

*Above: **Figure 3, Smoke Spread in a Longitudinally Ventilated Tunnel[3]***

More than 90 per cent of traffic accidents worldwide are due to driver error, and the introduction of automation in vehicle navigation thus provides an opportunity to reduce accidents and injuries. It is estimated that by 2030, connected and autonomous vehicles could save more than 2,500 lives and prevent more than 25,000 serious accidents in the UK alone[2]. However, the risks presented by the current state of autonomous technology have been highlighted by a fatal accident on 7th May 2016, where a Tesla Model S's sensors system failed to identify a large white 18-wheel truck and trailer crossing the highway. The car attempted to drive full speed under the trailer, with the bottom of the trailer impacting the windshield.

Tunnels present a number of specific safety challenges for autonomous cars. Their restricted geometry means that any lateral deviations due to incorrect steering could lead to collisions with one or more tunnel walls. Wireless channels, which can permit both vehicle-to-infrastructure (V2I) as well as vehicle-to-vehicle (V2V) communications, can be attenuated along a tunnel, leading to loss of signal strength. Global Positioning System (GPS) signals, required for satellite navigation systems, are disrupted in tunnels. However, the main risk with using autonomous cars in tunnels is that they may not operate in a safe manner in case of fire.

The most dangerous tunnel fires such as the Tauern tunnel fire in 1999 have involved heavy goods vehicles. In that respect, the introduction of V2V communications between heavy goods vehicles with automatic distance control as well as V2I warnings could potentially lead to enhanced safety in tunnels.

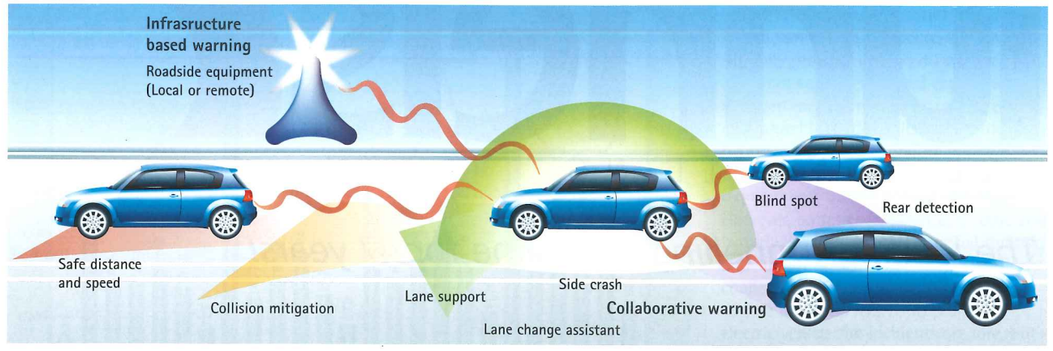
Should a fire break out in a tunnel, human drivers are assumed to remain in a clear (smoke-free) tunnel zone. Designers typically specify ventilation systems that either push the smoke-laden air downstream of the fire via longitudinal ventilation systems such as jetfans or Saccardo nozzles (Figure 3), or to extract the smoke locally via transverse or semi-transverse ventilation systems.

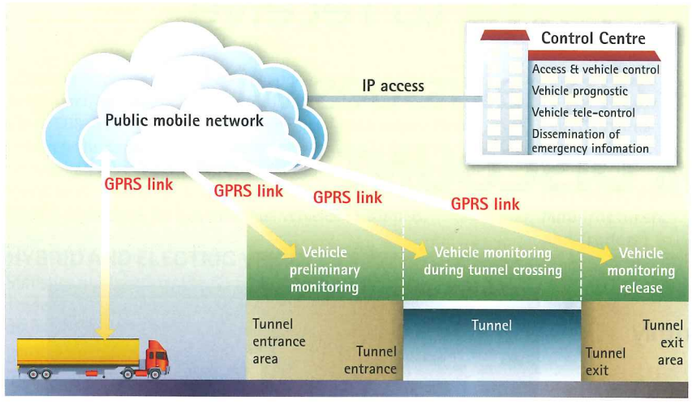
Autonomous cars cannot detect fire or smoke in the tunnel, and may therefore drive past a burning vehicle and into a dangerous, smoke-laden zone. It would be uneconomic and impractical to install fire or smoke detectors in autonomous cars to deal with this scenario, and in any case, such detectors may trigger too late to guide an autonomous car. Instead, the solution may be to rely on the V2I channels to transmit a warning about the burning vehicle, on the basis of fire and smoke detectors installed in the tunnel, as well as V2V communications between connected vehicles (Figure 4). Vehicle-mounted cameras can be programmed to detect tunnel lane closure signs as well as redirection signs to an exit ramp. There may be an opportunity for the tunnel operator to use the V2I channels during an emergency in order to direct vehicles: for example, in order to prevent vehicles from entering a tunnel, to stop them travelling any further into a tunnel, or to drive out via the main bore or through a ramp.

In the EU's Safe Tunnel research project, GPRS networks were proposed in tunnel entrance areas, within the tunnel itself and in tunnel exit areas, in order to communicate with suitably equipped vehicles (Figure 5). Tunnel operators can use the GPRS networks to impose lower speed limits and or safety distances between vehicles during emergencies, maintenance works and during periods when the tunnel equipment functionality is below the minimum operating requirements for safety. The EU's SAFESPOT research project reported improved V2I communications using the IEEE 802.11p protocol, an approved amendment to the IEEE 802.11 standard (Wi-Fi) which adds wireless access in vehicular environments.

The location of an incident within a tunnel could be transmitted from the tunnel detectors to the on-board computer. Although GPS reception is not generally available in tunnels, the satellite navigation systems may be able to use "dead reckoning" [using a fixed starting point and calculating vehicle progression based on factors such as speed], to work out the vehicle's current location and to base its navigation decisions accordingly. However, research is required as to how the on-board navigation algorithm should be programmed in order to maximise tenability. For example, if the incident is close to the exit portal and the burning vehicle is not blocking the lanes, it may be safer to simply drive out of the tunnel. In cases where a significant tunnel chainage is present downstream of the incident, it may be safer for the vehicle to stop, for the occupants to disembark and to evacuate from the tunnel. Because of the complexity of the decision-making processes involved, it is likely that driver and tunnel operator intervention will be required when driving through tunnels for the foreseeable future. It is interesting to note that neither the EU SAFESPOT nor the EU Safe Tunnel research projects permitted autonomous driving in tunnels, for safety reasons.

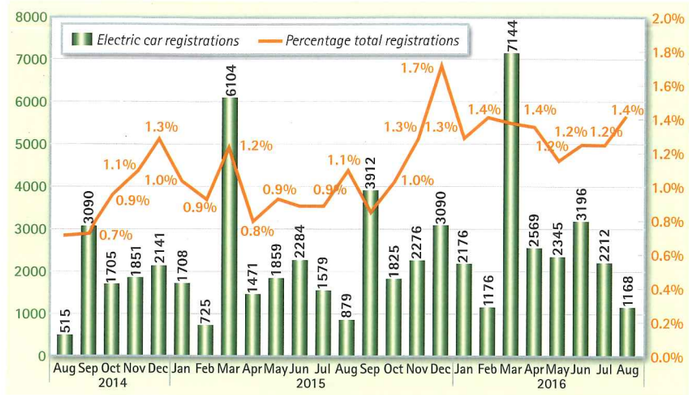
In order to deliver the required communication channels with autonomous and connected vehicles in tunnels, significant investment will be required by tunnel owners and operators to ensure wireless connectivity along the whole tunnel chainage. For short tunnels with clear lines of sight, the installation of broadcast antennae at the portals may be adequate, while leaky feeders and line amplifiers are required for long tunnels and those with restricted lines of sight. Since the wireless installation will be considered a safety-related device,





*Top: **Figure 4, Vehicle-to-Infrastructure and Vehicle-to-Vehicle communications[4]***

*Above: **Figure 5, Communication Architecture in the Vicinity of a Tunnel[5]***



adequate equipment redundancy and software verification may be required to achieve an approved Safety Integrity Level to BS EN 61508-6:2010. In addition, high-speed data connections between the tunnel incident detectors and the V2I channels will be required. The availability of funding for such infrastructure investment is likely to be a key prerequisite to providing safe driving conditions for autonomous vehicles in tunnels.

*Above: **Figure 6, Electric car registrations in the UK, 2014 - 2016 (Society of Motor Manufacturers and Traders)***

HYBRID AND ELECTRIC VEHICLES

Statistics published by the Society of Motor Manufacturers and Traders (SMMT) show that electric car sales in the UK have risen dramatically during the past two years (Figure 6). As a percentage of new car registrations, electric cars (including hybrids) now represent around 1.3 per cent of the total new car market in the UK. Bloomberg New Energy Finance predicts that electric vehicles will be 35 per cent of global new car sales by 2040[6]. Whilst in hybrid mode, emissions are significantly reduced for hybrid vehicles compared to conventional petrol and diesel models. These include reductions in carbon monoxide, nitrogen oxides and particulate matter. Small hybrid cars driven in electric-only mode typically produce around 40 per cent less CO_2 than equivalent petrol cars[7], and no nitrogen oxides or particulate matter are discharged from the tailpipe. Electric and hybrid vehicles can therefore improve tunnel air quality and reduce ventilation requirements during normal operation. However, batteries installed in electric and hybrid vehicles can pose a special fire risk, and such fires would present a significant challenge to fire-fighters.

Fire incidents related to plug-in electric vehicle fire incidents are rare, but there have been a number of documented instances of such fires. Most plug-in vehicle fires have been thermal runaway incidents related to lithium-ion batteries. Such batteries contain a flammable organic electrolyte which can be ignited by several methods including overcharging, charging at too high a rate, discharging at too high a rate and by damaging the battery during a crash or by impact with high-speed debris. Once ignited, such fires can be very difficult to extinguish, due to the risk of re-ignition.

In order to reduce the risk of battery fires in electric vehicles, manufacturers such as Tesla have designed liquid cooling systems in order to cool the battery cells; impact protection of the battery pack via metal plates; and a firewall to prevent a battery-pack fire from entering the passenger compartment. Some hybrid electric vehicles available in the market today use nickel-metal hydride batteries, which do not pose the same risk of

*Below: **Figure 7, Tesla Model S lithium-ion battery pack[9]***

thermal runaway as lithium-ion batteries.

An example of a plug-in vehicle incident is the fire which occurred on 1st October 2013 when a Tesla Model S hit road debris on a highway in Washington, US. According to the Fire Department incident report, initial attempts to extinguish the fire with water were unsuccessful, as the fire reignited underneath the vehicle after appearing to be extinguished. The Tesla battery pack is configured as a long, flat slab at the bottom of the car (Figure 7). The fire fighters had to use a jack to turn the car on its side and then cut holes in the battery's protective metal plate to apply water directly to the burning battery. Tesla subsequently improved the impact protection around the battery.

Tunnel fires are rare events, and fires due to vehicle batteries in tunnels should be even rarer – the author is not aware of any such fire being reported. However, electric and hybrid vehicle fires in tunnels would represent a significant challenge to fire fighters.

It may not initially be clear to the fire fighters that the seat of the fire is a vehicle battery. Ideally, graphite dry powder (class D) extinguishers should be used on lithium ion battery fires. If graphite dry powder extinguishers are not available, copious amounts of fresh water as a fine spray should be used to swamp the fire. However, the use of water on a lithium ion battery fire will generate hydrogen, which may in extreme cases increase the severity of a fire or cause an explosion if insufficient ventilation is provided in the tunnel.

Due to the physical restrictions imposed by the tunnel geometry, it may be difficult to use a jack within a tunnel to turn a burning car in order to provide access to the underside battery, and such a manoeuvre could potentially cause the fire to damage the tunnel wall.

Some manufacturers recommend disconnecting the battery before commencing fire-fighting operations, but that may be an unrealistic expectation. There may be a risk of electrocution, but that is limited due to battery current/voltage protection and fire fighters' personal protection equipment. Water is not effective at extinguishing a large lithium-ion battery fire. Due to these difficulties, fire fighters may simply decide to allow such a fire to burn out, depending on the outcome of their dynamic risk assessment[10]. In any case, fire-fighting operations to extinguish a burning vehicle's battery can be expected to last significantly longer than those for a conventional vehicle, exposing fire-fighters to additional risk.

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In view of the special risks involved, fire-fighting procedures should be developed for dealing with fires in electric and hybrid vehicles, and these should be incorporated in the training of fire-fighters in areas where tunnels are located. Ideally, such training should be combined with live and table-top exercises involving tunnel operators and other emergency services, including the police and the ambulance service.

An increasing number of tunnels are being equipped with fixed fire suppression systems, including high-pressure mist and low-pressure deluge. If promptly activated, such fire suppression systems can reduce the risk of fires spreading from one vehicle to the next. However, they would not be effective in extinguishing a shielded fire such as that originating from a vehicle battery. There may be a risk of re-ignition of a vehicle battery, and hence the fire suppression system should not be turned off until it has been ensured that the fire is under effective control[11].

NEXT STEPS

A lot is already known about the risks inherent in innovative vehicles, and much effort has already been expended in developing and implementing mitigation measures that have gone a long way towards addressing these risks. To date however, not much effort has gone into considering the specific risks in relation to the use of innovative vehicles in tunnels. It is hoped that a database of best practice can be developed, building upon the experience of countries that already have a significant proportion of such vehicles on their road network. Lessons learnt from future tunnel incidents involving innovative vehicles should be disseminated widely, to positively influence product design, tunnel installations and operation and emergency service deployment. Significant investment will be needed in order to ensure that tunnel safety is not only maintained, but even improved from today's levels

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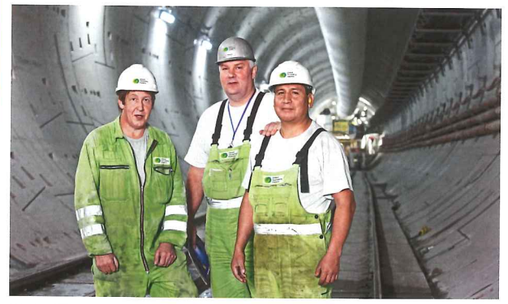

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4-5 May 2017
Zagreb, Croatia
ITA Croatia is organising the 7th International Symposium on Tunnels and Underground Structures in South-East Europe with the title SEE tunnel. With the support of ITA and our neighbouring countries the organisers are glad to open the possibility to speak about ideas, technical possibilities and financial interests.
www.promovere.hr/congress

Swiss Tunnel Congress
30 May - 1 June 2017
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.promovere.hr/congress

Rapid Excavation and Tunnelling Conference 2017
4-7 June 2017
San Diego, California
RETC 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 2017
Bergen, Norway
The theme of the 2017 World Tunnel Congress 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 2017
Sharm El-Sheik, Egypt
Recent rapid construction in Egypt has provided great opportunities for tunnel engineers to use their knowledge and talents to solve many challenging problems with innovative solutions and cutting-edge technologies.
www.geomeast2017.org

ICTUS 2017
28 August - 1 September 2017
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

Underground Infrastructure of Urban Areas
24-26 October 2017
Wroclaw, Poland
This ITA endorsed conference is being organised by Wroclaw University and the Polish Tunnelling Group. The conference will cover "discussion on various problems related To underground Infrastructure".
www.pbp-ita.pl/.org

Aftes International Congress
13-15 November 2017
Paris, France
The congress of the French tunnelling association returns to Paris in 2017. For more information, readers should contact Aftes, the French tunnelling association.
www.aftes.asso.fr

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.
www.stuva-expo.com/en/

2018

NASTT No Dig 2018
25-29 March 2018
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.
www.nastt.org

World Tunnel Congress 2018
20-26 April 2018
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. Experience true Arabian hospitality and enjoy Dubai, the world's most cosmopolitan city.
www.uaesocietyofengineers.com

2019

World Tunnel Congress 2019
3-9 May 2018
Naples, Italy
The World Tunnel Congress heads to the Naples in 2019 following a dramatic win at the vote at the event in San Francisco in 2016.
www.facebook.com/events/1753343481565751/

ECSMGE 2019
3-9 May 2018
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.

BTSYM: Tunnel Warfare. Tunnelling during the Great War
16 February 2017
Formed of volunteer sappers, tunnelling engineers, archaeologists, bomb-disposal experts and electrical engineers, the Durand Group specialises in the identification and exploration of subways and fighting tunnels used during WW1. This presentation will address tunnelling techniques during the first World War, mapping and exploration of underground space on battlefields, and EOD (bomb disposal).
Speakers: David Hedges, Bruce Simpson and Alan Thomas from Durand Group

Finsbury Park squareworks
16 March 2017
The Finsbury Park scheme being presented includes square works in the tunnel and works to shaft one, undertrack crossings and works to another shaft three to provide improvements to this existing London Underground Station.
Speakers: TBC

The Harding Prize
20 April 2017
The annual competition is named in honour of Sir Harold Harding, founder chairman of the BTS and is open to engineers aged 33 or under. Entrants must submit an original paper relating to any aspect of tunnelling.
Speakers: TBC

Joint BTS/BGA meeting - The Deoxygenated Gas Risk in London
18 May 2017
This meeting will look at the deoxygenated gas risk which may affect underground construction works in London. This has been the subject of recent research and tonight's meeting will cover this, current thinking and the practical aspects to be adopted on projects.
Speakers: Tim Newman, Geotechnical Engineer, Tideway Project

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: TBC

High Speed Railway Tunnel Projects & General Tunnelling Status in China
21 September 2017
This presentation will be given jointly by the China Railway Tunnelling Group Co Ltd (CRTG) Contractors & China Railway Engineering Equipment Group Co Ltd (CREG) TBM suppliers.
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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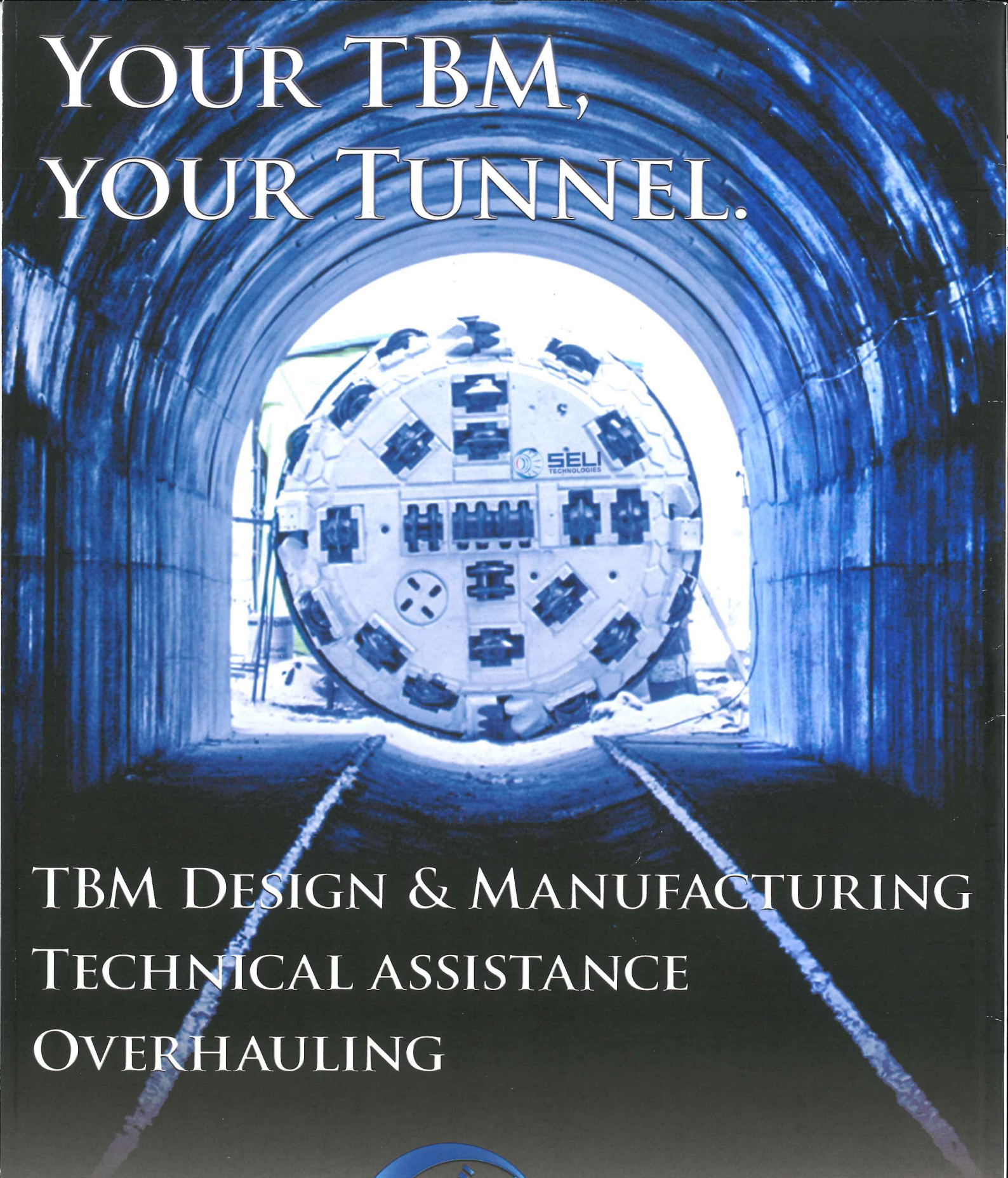

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