INTERNATIONAL EDITION
June 2016

Tunnels AND TUNNELLING

British tunnelling

Delhi Metro

Sprayed concrete

CERN CALLS

The scientists at CERN need ever larger tunnels

LEARNING THROUGH DOING

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

TODAY CELEBRATIONS are underway in Switzerland as the world's longest railway tunnel opens. It is 1 June, and stakeholders and political figures are attending a day-long programme of events at the tunnel, prior to a festival for the people involved in the project which is due to take place tomorrow.

The 57km twin tube Gotthard base tunnel is considered by some to be the first of the first of the "21st Century tunnels" and was brought into being to provide a relatively flat and low crossing of the Alps for freight and passenger trains. It will take significant amounts of traffic off the roads in the Alpine passes.

The project throws out impressive challenges pretty much wherever you look. Half a century from concept to realisation, 152km of total excavation, boreholes up to 2,000m deep, the 'hourglass sand' weathered dolomite of the Piora Mulde syncline, 2,300m maximum overburden.

Tunnels and Tunnelling reported in March 2011 that AlpTransit promised to deliver the tunnel to Swiss Federal Railways in May 2016. Again, impressive.

The industry is rightly celebrating, but it is also important to remember the failures and improve on past efforts.

In addition to the celebrations on 1 June, a more solemn ceremony was held on 31 May in remembrance of the nine people who lost their lives on the project. Four came from Germany, three from Italy, one from South Africa and one from Austria. The efforts at the Bodio site cost three lives, Faido two lives, Sedrun two lives and Amsteg one life. Traffic was halted and the names of the deceased were read out and a memorial plaque unveiled.

Any death on a construction project is a tragedy, but the industry is progressed by these technically challenging projects, and there is some solace to be had here. The safety culture in Switzerland has changed significantly in the last few decades, and especially since the start of the Alpine megaprojects and the breaking out of tunnelling into its own insurance category. Other changes include diesel particulate filters, restrictions on dry mix shotcrete, rear-view cameras on plant, fire-extinguishing requirements, working temperature and humidity limits. A lot of good things.

It is then worth looking to history to see the changes that can come from technical and cultural advancement. The first Gotthard tunnel, constructed over 100 years ago, resulted in 177 deaths for 15km of tunnel. The Gotthard road tunnel driven in the 1970s took 17 lives for a 17km drive. Hopefully the next generation of megaprojects can reach zero

Cover
This issue's front cover shows an existing installation at the LHC in Switzerland's CERN facility.

Next issue
In the next issue of Tunnels and Tunnelling we have the first part of a two part special on wartime tunnelling operations written by former advisory board chairman Myles O'Reilly, as well as well as a paper on the challenges of crossing geological fault zones.

This month...

20 YEARS AGO
British contractors are preparing for a bonanza of tunneling work for the foreseeable future after suffering a dearth of work once the Jubilee Line Extension was underway. In the short term they are bidding for the large interceptor sewers in Clacton for Anglian Water and Folkestone for Southern Water. London Underground is inviting bids for the upgrading of the Elephant and Castle station. And around Christmas time they are expecting bids for a tunnel under Ramsgate harbour. In summer next year work is set to start on the DLR extension to Lewisham.
Tunnels and Tunnelling, June 1996, p.9

30 YEARS AGO
The Soviet Union is believed to be building two massive seaside tunnels near its Pacific naval base of Vladivostok to conceal its nuclear submarines from satellite monitoring. A report in the Japanese newspaper, Sankei, noted for its intelligence coverage of Soviet and North Korean military affairs, said the tunnels can accommodate the world's largest strategic nuclear missile submarines of the 30,000t 'typhoon' class. The base is located at a place spelled phonetically as "Stoleklock", which according to the paper is not shown on any map available in Moscow. Other such caverns exist in other countries of the world. The use of massive underground rock caverns for unusual purposes is becoming a real alternative to surface facilities.
Tunnels and Tunnelling, June 1986, p.9

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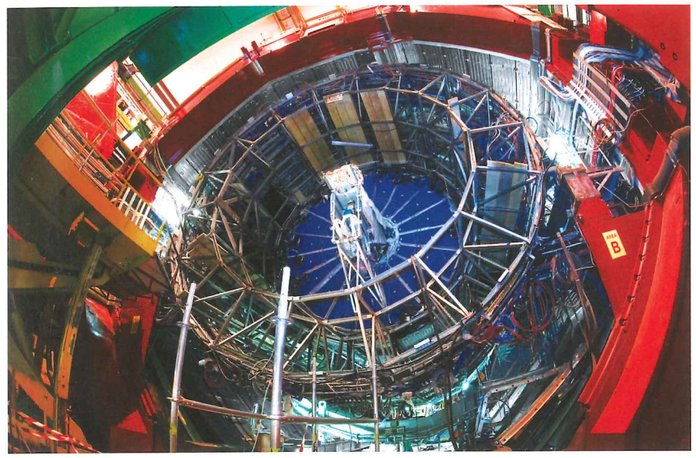

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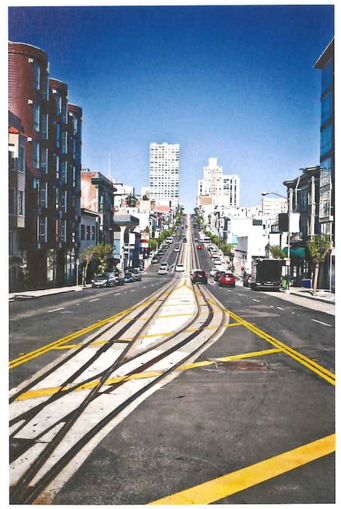

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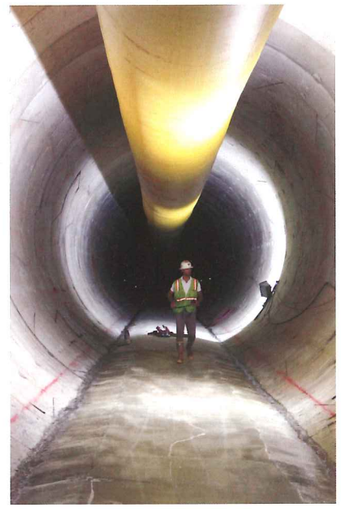


Key people in this issue

ROSS DIMMOCK, NORMET

KEITH BOWERS, LONDON UNDERGROUND

BILL GROSE, INDEPENDENT

CLAUDIO DIAS, CH2M

FILIPE MELLO, BAM-FERROVIAL-KIER JV

JOHN WALLIS, MOTT MACDONALD

PAWEL CZAJKOWSKI, CH2M

YASER MAQSUD, CH2M

PETR SALAK, DR SAUER AND PARTNERS

CELESTINO ELECTED ITA PRESIDENT, HAILS SUCCESSFUL WORLD TUNNEL CONGRESS

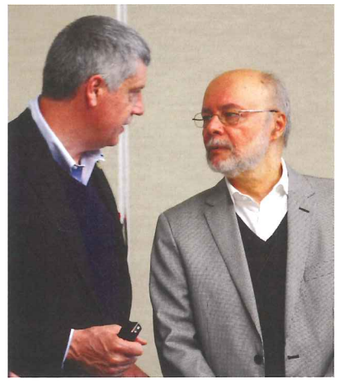
INTERNATIONAL — Tarcisio Celestino was elected president of the International Tunnelling Association (ITA) at the World Tunnel Congress in April. Celestino, a professor of geotechnical engineering at the São Carlos campus of São Paulo University takes the seat vacated by Søren Degn Eskesen, chief tunnel specialist for Danish contractor Cowi, who steps into the advisory 'immediate past president' position.

The term will last three years, with the next election coming in 2019.

Celestino, also the current and a past president of the Brazilian Tunnelling Committee, took aim at past failures of project design (elevated infrastructure) "in certain countries" that resulted in structures needing to be destroyed and undergrounded in later years. A waste of resources and effort.

He also argued that although the ITA and its various committees and groups have no legal power, the work it produces is often adopted by regulatory agencies for the betterment of engineering projects worldwide.

On the state of the organisation he now leads, Celestino said: "This is a very good moment for the ITA. The World Tunnel Congress in San Francisco was rather successful. The number of attendees, exceeding 2,300, is by far the largest in the history of the Association. Even when the event was previously organised in the United Sates the number was much lower.



Celestino (right) is active in the ITA's Working Groups and Committees

"This is an indication that WTC managed to bring new blood to the event. Exposing new people to information about the progress in the techniques for design and construction of underground works and about the advantages of going underground will bring a positive impact which will last much longer than the event itself.

"Never before has the WTC venue been so close to the Silicon Valley. The proximity was not only geographical. Interesting sessions on innovation on the use of information technology for tunnelling equipment and monitoring procedures were highlights of the event. The good news will be taken to the wider world by these new people. This is good contribution to improve the image of underground construction, not only for decision makers, but also for the agents responsible for licensing processes. Licensing has become a bottleneck for many projects, sometimes eliminating advantages of shorter construction time due to innovation of equipment and techniques."

Celestino concluded: "The new ExCo is open to receiving suggestions for the improvement of the Association management. We look forward to three years of fruitful work."

Alaskan Way Viaduct reopens after tunnelling

USA — The Washington State Department of Transportation (WSDOT) closed the SR 99 Alaskan Way Viaduct in Seattle for 10 days starting April 29 while the TBM mining the replacement road tunnel passed under the structure.

The machine successfully tunnelled through complex soils only 15ft (5m) below the viaduct's foundation – the closest the TBM will come to any structure at any point in its drive. Structural engineers with WSDOT completed a thorough inspection of the viaduct and confirmed continued stability of the ground and the viaduct.

WSDOT said it temporarily closed the highway so crews could more closely monitor the structure. The tunnel team originally planned to keep the highway closed until after the machine had completely cleared the viaduct, but the success of the tunnelling operation and the continued stability of the ground led to discussions of an early opening as work progressed.

Contractor Seattle Tunnel Partners estimated that tunnelling beneath the viaduct would take approximately two weeks.

"Closing a major highway is never easy, and the public deserves a big thank you for their patience and flexibility while this crucial work took place," said Washington governor Jay Inslee. "I would like to thank the WSDOT and STP project teams and construction crews on a job well done. To finish this piece of the project almost a week early is commendable."

On 18 May WSDOT announced the TBM had installed 300 concrete tunnel rings and mined more than 2,000ft (610m) from the launch pit, more than 20 per cent of the drive.

Construction union merges

GREAT BRITAIN — Construction union UCATT will join the larger general union Unite. The union made the decision in order to "preserve its existing structures and to maximise the representation of construction workers in all sectors".

UCATT will now enter into full negotiations with Unite. Once negotiations are complete a vote on a transfer of engagements of all UCATT members will take place.

Brian Rye, acting general secretary of UCATT said: "UCATT delegates listened to the arguments both in favour of remaining independent or a merger or transfer to Unite and decided that the best option for existing members and for all construction workers was a link to Unite."

Brockville restoration

CANADA — The Brockville, Ontario, City council voted April 12 to pursue restoration for the Brockville Rail Tunnel, the country's first tunnel.

A local group, the Brockville Railway Tunnel Committee campaigned for the city to reopen the 19th century tunnel as a tourist attraction and a walking/biking path. The city will tender to select contractors and suppliers for the restoration for the first phase: masonry repairs, rock stabilisation, work on the drainage system, concrete travel surface, lighting, ventilation, safety and security features, slope stabilsation, access ramp and landscaping features. The budget is expected to be CAD 2.5M (USD 2M), with an opening in summer 2017.

SR99 TRIBULATION RESULTS IN CRANES INDUSTRY JUBILATION

USA — The previously incapacitated Alaskan Way Viaduct Replacement TBM is a cause for celebration in other industries. Cranes company Mammoet was recently awarded the Specialised Carriers and Rigging Association's (SC&RA) Job of the Year Award for what is commonly known in the cranes industry as the "Tunnel Boring Machine Recovery Project in Seattle".

Mammoet, which is the world's largest service provider specialising in engineered heavy lifting and transport, brought home the award in the jobs over USD 2M category.

A spokesperson for Mammoet said of the project: "In December 2013, the world's largest TBM ceased operation 35m underneath Seattle after hitting a steel pipe damaging the seal ring and bearing block.

"It could neither be repaired underground, nor could it be easily retrieved. Mammoet was contracted to lift the 2,000t cutterhead from a 35m-deep shaft for repair and lower it back down once repairs were complete.

"Mammoet successfully and safely completed the task by designing and fabricating a unique custom-engineered gantry tower with the world's first hydraulic equalisation system, which evenly dispersed the forces exerted by lifting and tilting the load. It was a necessary innovation, as the gantry tower would stand on existing concrete piles used for tunnel stabilisation, which were not designed to support loads at height.

"The result was a 'self-balancing' tower gantry that ensured the stability of the entire lifting operation."

An ironworker with Mammoet USA ensures that a 32m-tall modular lift tower is running smoothly before it hoisted the front end of the SR 99 tunneling machine to the surface for repairs PHOTO: WSDOT

Fehmarnbelt conditional contracts signed

GERMANY/DENMARK — Conditional contracts have now been signed with the consortia chosen to construct the Fehmarnbelt fixed link. Following the previous announcement, pen has been put to paper. A slight delay caused the contracts to be signed at the end of May rather than mid-May. This was due to a complaint being received by the unsuccessful bidders, and time needed to be allowed for legal review. As it is an ongoing complaint, no further information was forthcoming.

The teams are also still waiting on a German construction permit, which depends on environmental approval.

The four contracts are: Tunnel North Contract; Tunnel South Contract; Tunnel Portals and Ramps Contract; Tunnel Dredging and Reclamation. The first three were signed with the Femern Link Contractors JV (FLC) and the last was signed with Fehmarn Belt Contractors (FBC).

FLC consists of Vinci Construction Grands Projects, Per Aarsleff Holding, Wayss and Freytag, Max Bogl, Bachy Soletanche, CFE, Bam Infra, Bam International, and Dredging International.

FBC consists of Boskalis International, Van Oord Dredging and Marine Contractors, Hochtief, and Zublin.

The Fehmarnbelt project aims to construct an 18km-long immersed tunnel between Denmark and Germany. Past estimates have put the project at USD 7.3bn.

TUNNELLING COMPLETES ON WEST ASHLEY SEWER

USA — Following a six-month excavation, the TBM drilling a new 1.6-mile (2.57km)-long wastewater tunnel in Charleston, South Carolina, has made its breakthrough, Charleston Water announced on 19 May.

This is the fifth and final phase of the USD 196M Sewer Tunnel Replacement Project, which began in the 1990s and is one of the largest and most costly infrastructure projects in Charleston Water System's 99-year history.

The new West Ashley tunnel will replace an existing tunnel that's in poor condition and too small for today's peak wastewater flows.

This creates a bottleneck that occasionally causes sewer overflows in low-lying areas of West Ashley.

The construction contractor is Southland Renda, a joint venture between Southland Contracting and Oscar Renda Contracting, who launched the 8ft (2.4m) diameter TBM in November 2015 from deep shaft at the Plum Island Wastewater Treatment Plant. From there, it drilled under the Wappoo Cut to another deep shaft off Albemarle Road. The tunnel is some 125ft (38m) deep.

Excavation of the West Ashley sewer tunnel project took six months, breaking through on 19 May

The contractor will now install a pipe in the tunnel, build a pump station at the treatment plant, and connect the new tunnel to the existing sewer system off Albemarle Road. Construction is expected to be complete and the tunnel put into operation in late 2017.

The design team includes Charleston Water System staff, Black & Veatch, Hussey Gay Bell, and Hazen and Sawyer.

Investment group proposes Montreal light rail system

CANADA — CDPQ Infra, a subsidiary of Caisse de dépôt et placement du Québec, unveiled plans for a 67km light rail system in Montréal on April 22.

The Réseau électrique métropolitain (REM) will link downtown Montréal, the South Shore, the West Island (Sainte-Anne-de-Bellevue), the North Shore (Deux-Montagnes) and the airport in a unified, fully-automated system comprising 24 stations and operating 20 hours a day, seven days a week.

An underground component is included in re-purposing the existing Mount Royal tunnel.

CDPQ Infra, established in July 2015, said upon completion REM will be the third largest automated transportation system in the world after Dubai (80km) and Vancouver (68km), and just ahead of Singapore (65km).

REM represents the largest public transportation infrastructure since the Montréal metro, inaugurated in 1966. The new network represents an investment of approximately CAD 5.5bn (USD 4.2bn). La Caisse is willing to commit CAD 3bn (USD 2.29bn) to the project. The proposed financial structure also requires investments by the governments of Québec and Canada and the decision to move forward with the project is conditional upon their financial participation.

"A network as significant as the one we are proposing could potentially add more than CAD 3bn (USD 2.29bn) to the Québec GDP over four years.

"We also expect close to CAD 5bn (USD 4.2bn) in private real estate developments along the chosen route," said Christian Dubé, Executive Vice-President, Québec at la Caisse.

The plan also includes reserve capacity to meet future needs, with five potential stations envisioned for areas such as McGill University and Université de Montréal.

CDPQ Infra will begin a consultation process with various stakeholders in the coming weeks and plans to submit this project to the environmental impact public hearing (BAPE) process at the end of the summer.

The group said, "if all these steps are taken successfully, construction is currently expected to begin in the spring of 2017, so that the first trains can be in service towards the end of 2020."

Eglinton Crosstown western tunnels complete

CANADA — Tunnelling is now complete on the 6.2m-long western segment of the 10km tunnel of the Eglinton Crosstown Light Rail Transit (LRT) line, the Ontario Ministry of Transportation announced on May 10.

Two 6.5m-diameter TBMs boring the western segment tunnels, arrived at Yonge Street having travelled 6,419m from their launch at Black Creek Drive in June and September 2013.

Each TBM installed 25,647 precast concrete tunnel segments, manufactured by Decast, formerly Munro, which formed a total of 4,279 rings.

Metrolinx awarded the first of two tunnelling contracts for the Eglinton-Scarborough Crosstown tunnel, worth CAD 320M (USD 328M), in September 2012 to Crosstown Transit Constructors, a joint venture of Obayashi Canada, Kenny Construction, Kenaidan Contracting and Technicore Underground.

"We are making considerable progress on the Eglinton Crosstown LRT line," said Ontario's minister of transportation Steven Del Duca. "The completion of tunnelling from the west to Yonge Street is a significant step for the project and 19 kilometres of new rapid transit for Toronto."

An Aecon-ACS Dragados Canada JV launched two more TBMs on the Eglinton Crosstown LRT project in September 2015, which are tunnelling westbound from the launch shaft located east of Brentcliffe Road towards Yonge Street.

The new LRT line will have a total of 25 stations and stops along Eglinton Avenue between Weston Road and Kennedy Station, and LRT is one of the largest public transit projects currently under construction in Canada.

ENVIRONMENTAL REVIEW STARTS FOR HIGH SPEED RAIL THROUGH SAN FRANCISCO

USA — The California High-Speed Rail Authority (CHSRA) issued a Notice of Preparation to initiate a project level environmental impact report (EIR)/environmental impact statement (EIS) for the approximately 51-mile (82km) San Francisco to San Jose project section on 9 May.

At the same time, federal partner, the Federal Railroad Administration (FRA) issued a new notice of intent to initiate the federal environmental review process for the project section.

The preparation of the San Francisco to San Jose environmental document for the blended system will involve a scoping and public outreach process; development of preliminary engineering designs; and assessment of environmental effects associated with the construction, operations and maintenance of the high-speed rail system including track, ancillary facilities and stations, along the Caltrain corridor. A formal comment period related to public scoping has started, allowing for public comments to be received until June 10.

The San Francisco to San Jose Project Section is part of the first phase of the California high-speed rail system connecting the cities of San Francisco, Millbrae (San Francisco Airport) and San Jose on an electrified Caltrain Corridor with proposed stations at San Francisco 4th and King and/or Transbay Transit Center, near the San Francisco Airport (Millbrae) and San Jose.

The Transbay Transit Center Program is being developed by the Transbay Joint Powers Authority, and currently is in phase 1 of construction.

Phase 2 includes construction of the Downtown Rail Extension (DTX), including a new underground Fourth and Townsend Street Caltrain station; completion of the

San Francisco

Transit Center's train station. DTX will extend Caltrain commuter rail from its current terminus at Fourth and King streets to the new Transit Center. It will also deliver the California High-Speed Rail Authority's future rail service to the Transit Center.

A team led by Parsons Transportation Group has substantially completed work on preliminary engineering of Phase 2. The DTX was originally scheduled for completion in 2019; however, work is on hold due to a significant funding gap, according to the San Francisco County Transportation Authority, which said, despite the stall, work continues on the Supplemental EIS/EIR and coordination with Caltrain and the California High Speed Rail Authority.

The 1.3-mile (2.1km) extension (1.95 miles [3.14km] of total construction length) will be constructed principally below grade using cut-and-cover and mined tunnelling methods underneath Townsend and Second Streets. The project includes the underground station at Fourth and Townsend streets, six structures for emergency exit, and ventilation along the alignment, utility relocation and rail systems work.

Letter

Dear Sir,

I refer to the article on Czech hand mining techniques in Tunnels and Tunnelling International, February 2016.

It was interesting reading the article as it is equivalent to what might have been written 50 years ago for places like UK and Japan and others. However, I can't think why Tunnels and Tunnelling published such an article.

You are going to be criticised by others for publishing outdated information and does not meet current standards. From most European standards men are not allowed to work in the kind of diameters set out in the article. After all, the Czech republic is adjacent to Germany, which is definitely up to speed, and there is plenty of cross trade.

I think if you publish an article like this, which is interesting in giving a understanding of the state of play, you need to have a disclaimer.

Perhaps you can have an independent reviewer make some comments, which don't have to be overly critical, but pointing out the practices are not state of the art etc.

In some ways it raises the question of why outdated practices are still in use with all the information and H&S rules in force in the EU.

James Thomson
Jacked Structures

In response...

Dear James,

Thank you for your letter regarding the article on Czech hand mining techniques in Tunnels and Tunnelling February 2016.

We are an international tunnelling magazine and are happy to include articles on international practice. Articles of this type illustrate how interpretation and application of Health and Safety varies across Europe and the world.

A member of the Tunnels and Tunnelling Editorial Advisory Board reviewed the article prior to publication.

As chairman of the board I am comfortable in the magazine containing such articles which reflect what is happening in different countries.

Eddie Woods
Editorial Advisory Board Chairman

Correction

Tunnels and Tunnelling erroneously printed that Jacobs Engineering was responsible for the design of San Francisco's Bay Tunnel project (see Tunnels and Tunnelling International, February 2016, p.10).

The designer was in fact McMillen Jacobs Associates and the tunnel was subsequently named the ASCE Region 9 Outstanding Water Project for 2015.

The Bay Tunnel was completed on 20 May 2015 within the baseline schedule and below the baseline project budget.

ITAYM GROWS UP

The *International Tunnelling Association's Young Members* (ITAYM) group has voted in its second steering board. And as the fledgling assembly passes from an inaugural leadership pulled together from a few like-minded individuals to a full democratic committee, *Tunnels and Tunnelling* speaks with the person who started the whole process: Petr Salak

THE JOURNEY BEGAN a little over three years ago. Salak, an engineer with Dr. Sauer & Partners based in the UK, was chairman of the British Tunnelling Society Young Members (BTSYM). The group had been successful under the leadership of Kate Cooksey, its founder, Anita Wu and Tom Kavanagh, the third chair just prior to Salak. Predominantly the group had been getting involved in raising awareness of tunnelling as a profession, and brining young tunnel professionals and students into the activity spheres of the BTS.

With its day-to-day activities progressing, Salak says he had the idea to co-operate with other organisations. While the Norwegians also had an active Young Members group around this time, Google failed the BTSYM chair and it seemed the BTSYM was alone as a group for young tunnellers. A plan was hatched.

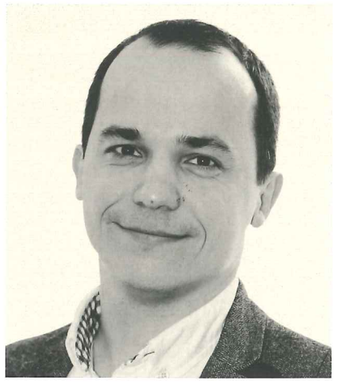
"I didn't want to go to each tunnelling society and say 'you should do what we are doing,'" says Salak. "It made sense to start at the ITA. So with the help of Martin Knights [CH2M] and Damian McGirr [Donaldson Associates] I sent a proposal to then-president of the ITA In-Mo Lee."

Permission was given to present at WTC 2013 in Geneva – a very quick turnaround by association standards – and the two prospective ITA presidents (Søren Eskesen and Markus Thewes) both gave the group their blessing. By the following year, a budget had been approved. Again, remarkably fast.

The steering board was elected, socials were arranged, and national young member groups began to spring up all around the world. There were around 25 groups at the last count.

KEEPING IN TOUCH

But for Salak, the most important function of the group is on the networking side. "There are two moments that stand out for me in my time at the ITAYM. The first was when I met an Argentine engineer at an event. He was interested in tunnels but had no specific education in underground construction and had not worked on a tunnel project.



Petr Salak

We were able to point him in the towards training programmes and tell him what support he might get. He earned a scholarship and now studies in the US.

"The second story is of a young Dutch engineer. He was fairly nervous to come to his first WTC. He didn't know anyone, and wasn't sure how he would make the most of the show. Fortunately he come along to our social on the first night, he mixed with the 120 young professionals and students there, and he had company and ideas for the rest of WTC. Frankly, I was nervous at my first show. I think we all were."

Salak hopes that the ITAYM will be able to drive youth participation in the ITA's Working Groups and Committees, and some success has already been achieved in this. With Salak in ITACUS and Jurij Karlovsek, the immediate past chair of ITAYM in ITACET and BIM, among others, the first wave of young members is getting involved in ITA activities.

There has been criticism, however, from some corners of the ITA establishment – people asking what the need is for a group that advocates and encourages young tunnel engineers. "The ITAYM is specifically targeting the next generation of tunnel engineers. Many of the existing organisations and committees comprise members that have long been in the industry.

"Bringing in fresh ideas and new ways of thinking can only be a good thing."

NEXT STEPS

With the start up tumult over, and the interim steering board disbanded, the first elected ITAYM Committee has taken its place. It will face significantly different challenges to those faced by the path-finding steering board.

"When you establish something, it's difficult to convince people to get on board, but if you succeed in that you grow quickly, says Salak. "We are past the crazy part, and now the ITAYM needs to deliver. We covered a lot of ground in the last three years – helping set up new Young Member national groups; setting up the ITAYM structure; convincing people that it was a good thing. However there is still plenty to do. We want to prepare plans for how to keep feeding young members into committees and working groups, get things running, and generally make sure the ITAYM continues smoothly."

The group is also now at a point where it can draw on the input of hundreds of organised young engineers around the world. With around 25 national groups, even with conservatively low estimate of 10 members per group, there will be a lot of opinions. At WTC 2016, attendees of the ITAYM general meeting were split into groups to brainstorm a list of requirements that they felt their national groups would prioritise. This long list is the first step in widening the scope of the ITAYM.

"That is something that perhaps we should have drawn on earlier," says Salak. "We had this pool of resources available to us, but we kept all of the work among six or seven people. But then again, when you are starting up and trying to find an identity, perhaps there is a risk of diluting your goals. Hopefully now is the right time and the new committee can properly make use of the network we've built."

Salak ends saying that it has always been about the community, and he particularly thanks Søren Eskesen, Olivier Vion, Alexandre Gomes, Martin Knights, Damian McGirr, Jurij Karlovsek, Nichole Boultbee, Sindre Log and Lasse Vester and everyone who made the ITAYM happen

Left: Scottish politician Keith Brown, who has responsibility for infrastructure, investment and cities in the devolved parliament, recently visited the Shieldhall Tunnel project in Glasgow. The GBP 100M sewer project will run for 5km and will be 4.7m in diameter. The first 250m of the tunnel, and the launching chamber, are open cut. The main bore is being driven by TBM

H+E: Specialist for spatial restrictions

TORONTO/CANADA. The Toronto-York Spadina Tunnel is an 8.6 km subway extension that includes six new stations. It will connect the city of Toronto to the regional municipality of York and offers a transit alternative to the burgeoning communities in northwest Toronto and to the north of Toronto.

Two vertical conveyors and vertical storage units by H+E Logistik GmbH, installed in 2013, ensure a reliable overburden removal capacity of 500 t/h. They transport material vertically out of the shaft and provide an optimum conveying solution even in projects that are characterized by spatial restrictions, like the Spadina Tunnel.

PROJECT DATA/VERTICAL CONVEYOR:

- Belt Width: 1,200 mm
- Height of Lift: 23 m
- Capacity: 500 t/h
- Installed Power: 1 x 160 kW
- Installation: 2013

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GOVERNMENT LEADS ON STRATEGY

Bill Grose calls for industry to keep up with government movements towards strategic infrastructure planning

Bill Grose
Bill Grose is a chartered independent civil engineer and a past chairman of the BTS

IN MARCH 2016 the UK Government published the National Infrastructure Delivery Plan 2016-2021. Should this matter to tunnellers in the UK? Yes it should, as it's another major step forward in the transformation of the way that economic infrastructure (transport, energy, water supply, waste management and telecommunications) is planned and delivered. This is the best chance we have had to lose the "boom and bust" cycle of tunnelling work and replace it with continuity. This will be a great step forward but it will require us to play our part too.

The idea of a strategic approach to infrastructure planning is not new. However, with the Coalition Government in 2010 came a resolve, not only to take a strategic look at infrastructure planning, but also to tackle the relatively high cost of building the UK's infrastructure and to improve productivity in the UK. In 2010 the first National Infrastructure Plan (NIP) was published, hot on the heels of the recommendations for saving money (the IUK Cost Review, published in December 2010). Since then the NIP has been updated several times, and the Cost Review has led to a number of guidance documents aimed at improving the UK's efficiency and our clienting and delivery capabilities.

The two government bodies leading the work were Infrastructure UK (IUK), a part of Her Majesty's Treasury, and the Major Projects Authority (MPA), part of the Cabinet Office. On 1st January 2016 these were merged into one organisation, called the Infrastructure and Projects Authority (IPA), reporting to both HMT and Cabinet Office, with the brief to improve delivery of infrastructure. The IPA's new report addresses not only economic infrastructure but also housing and social infrastructure such as hospitals and schools.

Working alongside the IPA is the newly created National Infrastructure Commission, currently under the chairmanship of Lord Adonis. The precise terms of reference of the Commission have yet to be worked out but essentially it is there to provide expert independent advice on pressing infrastructure issues and to help make planning policy more responsive (and hence more efficiently deployed). It is intended also to provide a structure for better dialogue between government, politicians, the infrastructure industry and the public.

So, what does all this mean to tunnellers? It means that the pipeline of UK infrastructure work into the future is more visible than ever before. And lots of it involves tunnels. You no longer need to guess or make dozens of phone calls to find out what's the plan – you can read it on line.

It also means that the public is better informed about the benefits of infrastructure, and can better understand the link between disruptive construction works now, and improved prosperity, job prospects and standards of living in the future. London's Olympic Park was a success, Crossrail is a good news story already (and not even opened yet!) and the talk of the future includes HS2, HS3, Crossrail 2, and many others.

But it also means that the construction industry needs to step up to the plate and deliver. Construction costs keep going up – largely in line with inflation at the moment, but why do they go up at all? We should be driving costs down, as virtually all other industries do.

We also need to improve productivity and build capacity in the industry – through better training and staff development, better knowledge management, longer-term employment prospects for workers, and improvements in health & safety. We need to build on the government/public sector/private sector dialogue that is currently happening, building strong and transparent relationships between the different sectors and organisations. We need to be quicker to embrace technology and new ways of working, and cleverer with it, learning from other industries.

The days of confrontational contract management need to be put behind us. The future has to lie in collaborative win-wins, not entrenched battles. So, the Government would say that it is very active in changing things for the better – we must ask ourselves what are we doing to improve our industry, and will it be enough, quickly enough?

Bill Grose is an independent Chartered Civil Engineer running his own practice, and a past chairman of the British Tunnelling Society. He is currently advising on several major infrastructure projects in the UK and overseas. He founded and led Arup Tunnelling for a number of years, was a reviewer and co-author of the insurance Tunnelling Code of Practice and was part of the HM Treasury team writing the 2010 Cost Review. He is a Fellow of the Institution of Civil Engineers where he served two three-year terms on Council and is currently a member of ICE's Public Voice Committee

BTS CHRISTMAS DEBATE

In December 2015 the *British Tunnelling Society* met to debate the assertion: "This house believes further development of SCL for complex urban tunnels is the best way forward for our industry". The rapporteur is **Paul Perry** of *Donaldson Associates*

A PACKED TELFORD THEATRE at the Institution of Civil Engineers heard the BTS annual Christmas debate with regards the motion "This house believes further development of SCL for complex urban tunnels is the best way forward for our industry". The chairman for the evening, Roger Bridge, introduced Keith Bowers of London Underground who was proposing the motion, and Ross Dimmock of Normet UK who was opposing it. For many in the UK, SCL has become the default method of tunnelling to allow projects to go forward. The speakers this evening are endeavouring to convince you that their view is the best way forward.

The chairman advised the audience that the views are slightly polarised and not necessarily the views of the individuals. Then followed some technical difficulties and Ross asked if we could have the lights out so he could present in anonymity but the rapporteur thinks he will have chosen to change his name after tonight. The chairman balanced this by saying that we should appreciate that both speakers had much knowledge of the subject and therefore gives them the ability to argue either side of the case.

He went on to say that it was almost considered to give the vote to start with as to who opposed and who supported. He implored that the audience listened to what they have to say, as they know their subject well.

The Chairman then introduced the speakers: "Supporting the motion we have Keith Bowers. He is the Head of Tunnels for London Underground. He has engineering accountability for the plethora of tunnels and shafts of the world's largest and oldest mass transit railways, as well as responsibility for new tunnel works and Crossrail too. He has his views on SCL, some of which he will elucidate tonight."

"Ross Dimmock is a Director of Normet UK, a Finnish specialist tunnelling and mining company, in the last 27 years; Ross has worked exclusively on SCL projects globally and in the UK, both on the design and construction side. He too has views on SCL and we are privileged to hear these tonight."

The chair explained that the format for the evening was that each of the speakers will have 20 minutes to present their case, and have elected not to have "seconders", that is they are sure of their science. There is then a 20-minute debate and finally a five-minute summing up with a vote taken at the end to see who has won.

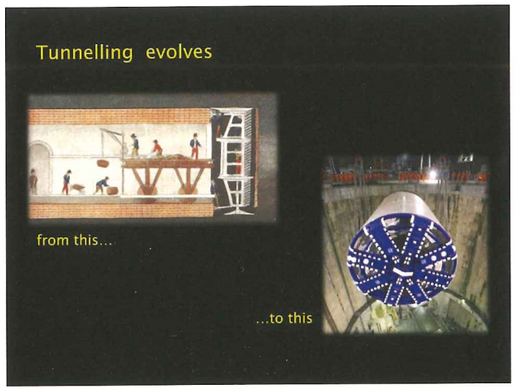
The meeting started with Bowers' observation that the audience were once again gathered in the Telford Lecture theatre to discuss SCL, previously known as NATM.

Bowers then started by taking the audience on a journey, referring to a section of tunnelling history by indicating figures of two recognisable tunnelling machines, a couple of centuries apart, both under a city and both revolutionary at the time.

Bowers suggested that tunnelling evolves and that tunnelling practice changes. A parallel was drawn between SCL tunnelling and SCL tunnelling in the UK, which has occurred over the careers of some in the audience. A pause was suggested to reflect on that.

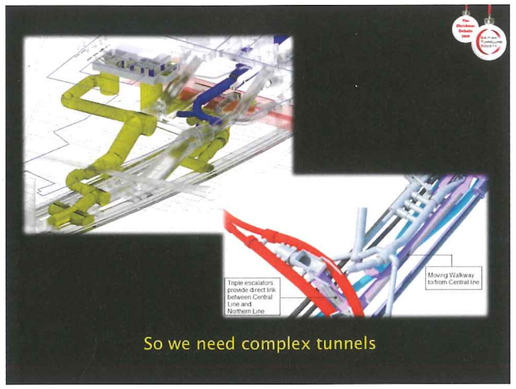
Reference was made to Channel Tunnel with its sprayed concrete for primary support, and dry mix just for temporary works purposes, all in all deemed a successful project. Similar construction, at Round Hill, was then referred to with the use of a dry mix for temporary works support and cast-in situ linings used to ensure the appropriate support. Noting this, the presenter alluded to modest issues with the permeability and around the steelwork used within the tunnel.

The presenter showed a few images that might have been construction practices of the norm then which are now not considered the good practice now: for example the operative next to the exposed face beginning to start to spray next to a cherry picker moving around behind him. The speaker asked the audience to consider that times have changed, practice had got better, as an industry got better at creating the product the client wanted, such the shotcrete technology has moved into permanent works and some fine examples were shown.



Right: ***The development of tunnelling shields in London through the centuries***

Future cities need complex underground networks



So we need complex tunnels

The audience were asked to reflect on CTRL (HS1), and it was noted that the industry had got smarter with design being better, economic and benefited a gain in confidence from good case histories demonstrating that not all shotcrete was to degrade into gravel that has been supposed, and some primary linings had been incorporated into schemes as permanent work with efficiency gains such as on the North Downs Tunnels.

The audience were then asked to consider a London Underground project, executed recently, where mechanised SCL tunnelling was used in a location where previously only hand tunnelling was considered possible or practical as a solution.

It was stated that this was quite a journey travelled with this technology, and that these illustrated how it had developed over a quarter century or so.

The presentation turned to the next aspect of the proposition, that was complex urban tunnels, and whether these are required. The audience were asked to consider this noting our cities today. A typical London street scene was shown with significant numbers of people and it was noted that this is actually a common problem in cities across the world. Cities in India was quoted as a good example, here. Global urban growth and intensity was suggested as being unprecedented in history.

The audience were asked to focus in on London as an example. It was noted that in October 2015, LU had 25 million passenger journeys in a week recorded on the London Underground network. Every year, almost every week, LU is surpassing records with number of people on the system and it was suggested that London needs to build the kind of infrastructure involved in today, for future capacity in decades and very possibly required for centuries. Projects need to consider this a long way ahead, speculate a bit, as this architect has done on what the form of the future city might be like.

The presenter suggested that there is going to be an increased demand on the underground space, although it was noted that the vision shown had the architect seeking to prioritise on the clear space on the surface, associated with more tall buildings, all leading to more people wanting to get in and out of cities, that necessitates not just more transport systems, but more sanitation systems, more power supply systems, all the elements of urban infrastructure and needed underground. And that means inevitably projects will have to deal with complexity. It was suggested to the audience that this results in projects such as Bond Street Station Upgrade, which are very complicated structures, and involve winding new tunnels around old, rather like organising a plate of spaghetti

There is a bit of context. So the question was asked what is the best way forward for the industry. The presenter, then donning a familiar London Underground hat, asked what the smart thinking client looks for in his future tunnelling.

Above, left: ***The needs of futuristic cities are dependent on the use of underground space***

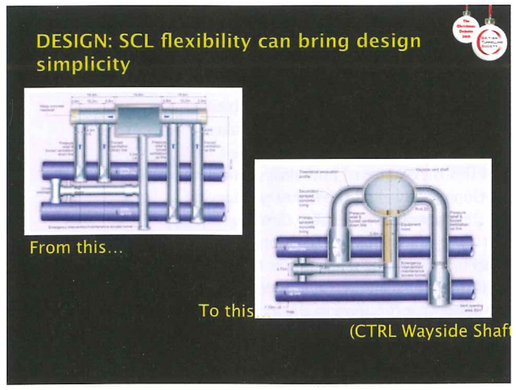
Above, right: ***New tunnelling work for the Bond Street Station Upgrade***

Below: ***Flexibility of design can afford structural simplicity***

It was suggested that clients know that the demand is growing and that the worlds resources are finite and more particularly the resources that fund are finite. We will have to work harder to achieve more. The response to the question "So can SCL help us with this?" and the speaker suggested that SCL presents a very powerful tool to help solve this.

The audience was asked to initially consider design, noting that a few design options had been tried by London Underground on a number of projects, with flexibility, with shape, elegant solutions, working around constraints, bring design simplicity such as the CTRL example in a shaft. The arrangement below shows traditionally built tunnels and shafts. The shapes were adapted to suit the location, connections changed and the flexibility of architecture was achieved because of the SCL approach used.

The question of efficiency was raised with the speaker referring to a number of his own photographs of reinforcement in concrete structures that unsettled him. The speaker suggested that a number in the industry have concerns on efficiency in this regard and would like to improve. It was



accepted that in some cases the amount of concrete and the amount of reinforcement deployed were said to satisfy the design challenges the industry have set ourselves. The speaker suggested that this is where the industry is not perfect in what is done but then the motion is about the scope for development. Here is an example, in what has been done on Crossrail in association with Cambridge University with the use of fibre optic monitoring around openings in large tunnels. This system is installed in the shotcrete and observations are then undertaken. This then reduced the extent of the thickening needed in the lining at certain locations.

It was then suggested that the industry has got much better in creating options and as well as creating durable solutions. As an example, the speaker referred to waterproofing, a subject of great concern dear to an operator of a mass transit railway. Waterproofing detailing and installation has much improved in what can be offered as permanent works. The speaker accepted that there are still some questions, such as waterproofing delaminating, and various other possible criticisms. However a palette of choices are now offered for the end user and it is this that has opened up new possibilities.

And then the speaker referred to construction. It is now possible to have machines that can mine uphill with the ability to mechanise now in really quite difficult places; places where works used to have to put men, and it is really valuable that the industry has found methods where the required works have got men out of some of the most exposed environments. In today's industry, there are a number of environmental controls as dust and noise are significant issues for the project. The industry is developing better plans and better control systems and therefore there much less a constraint on what is done than perhaps a few years ago. In the last few days London Underground have tunnelled under another escalator, under the Bakerloo Line at Paddington.

It should be noted that industry is getting much better at ground movement control and the speaker noted that ten years ago it would not have be possible to undertake some of the works undertaken in today's projects. It was suggested that this is evidence of how skills are developing as well as the industry achieving the permanent works quality through factory style materials preparation. Project expectations can be a lot greater than they used to be. The speaker suggested that the largest contribution to the industry as a whole has been the RESS culture that has come out of SCL work. This is now seen spreading into other areas of what is undertaken which the speaker suggested shows positive progress and opportunity.

The speaker then mentioned the important issue of safety and the way that has been a changing area for the industry at times. Then again tunnelling practices are changing and new improved technologies are being developed which has allowed the industry to control the risks so much better and prevent projects getting into some of the situations that occurred in the past.

The speaker decided to change tack, to finish. Referring to the chair's mention of the triennial summit at the ICE linked to the climate change discussions at the UN, questions for the tunnelling industry have been raised with the future. The speaker referred to carbon emissions. It was noted that seven per cent of global CO_2 emissions are from concrete (aviation is three per cent in comparison). In detail, cast iron produces at a rate of 2.8kg of CO_2 per kg of material, concretes are a lot lower than cast iron but are still significant at 0.1 to 0.5kg of CO_2 per kg of material. This is an issue for the tunnelling industry.

In the UK, certain research and industry are working very hard on recycled construction materials which are carbon neutral noting that client's are now considering how the carbon in the works

Questions from the floor

John Westwood: Have we made structures too complex that designers have difficulty to meet the codes of practice, and element all the risks, and the cat three checkers experience problems in sign this off?

Keith Bowers responded; We get confused about the requirements and methods of design and get strange outputs. He said he was in a privileged position where he sees designs from different people, executed under different procurement methods, constructed by different people and he sees a lot of doubt with linings much thicker and more heavily reinforced. Therefore it is correct to probe methods and design approach. Issues are much about much about behaviour and context you put to do their work, and requirements we put them in. Behavioural challenge is deeper than the design codes we use.

David Hindle (OTB, retired): A comment on Finite Element Analysis being inappropriate for use in the design of SCL, with thicknesses becoming great (up to 1m thick was quoted), which is likely to prevent SCL developing and the industry reverting to SGI lining. We invented aeroplanes to travel at supersonic speeds, racing cars subs and jet engines economise on efficiency, on tunnelling we have made it 1m thick in 30 m of London clay wrong design tool or we do not know how to use it SCL going nowhere, or go back to cast iron.

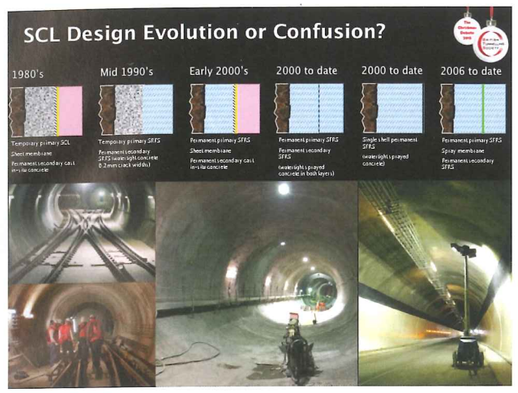
Bowers responded; Sympathy our behaviour as an industry way we prescribe the mechanics calibrate design more trials more testing approaches to projects in pasts way we learned must reflect not a barrier to potential achievements.

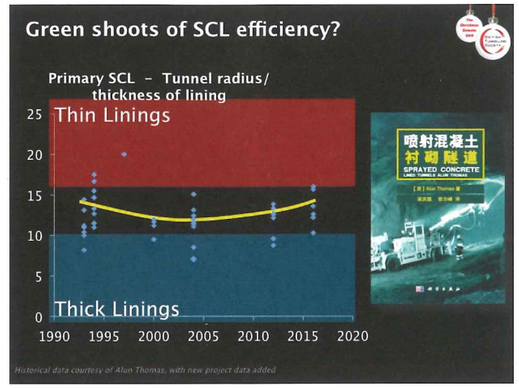
Colin Mackenzie (retired): Do not understand why we move away from SGI referring to Pliny, thickness of concrete lining arises to uncertainty on design, risk etc, SGI is easy to compare with examples took the loads from time, SGI does not have that. A young intern studying accountancy and he looked at comparison of SCL and SGI works. SPL was much more expensive.

Bowers responded; Cost has not really been discussed tonight, can construct cost options, closer, looking for benefits as simplicity, thinner and more efficient elements cost not the dominant driver, it is a factor amongst a number. More nervous about the carbon and the cost.

Summations were made and the chair then took the vote and a show of hands passed the motion with a substantial majority, voting strongly in favour of the motion "This house believes further development of SCL for complex urban tunnels is the best way forward for our industry"

Rapporteur: Paul Perry, Donaldson Associates





Above, left: ***Evolution of typical lining designs***

Above, right: ***Slide showing SCL lining thickness over time***

can be quantified. The speaker suggest that once we have that measure then it is a very small step to start to use that as a control, a consideration in procurement perhaps.

The speaker then reflected on what does that mean for our SCL noting a typical SCL mix.

The speaker suggested that consideration to replace the materials to improve the situation, ie replace OPC cement with a geopolymer, cement alternatives that do not carry the carbon penalty, they have higher strengths for example. It was also suggested to consider the aggregate as well with recycled plastics, and replace the steel with carbon fibre reinforcement.There are a few things worth looking at that are potential for the future.

There are now many structural composites and why could these now be considered for efficient tunnel linings.

Bowers asked the audience if these were technologies for the future and suggested that some of these can be implemented on a practical approach one element at a time. He referred to a bridge in Japan, which is thin and fine.

In conclusion the speaker asked "Are these technologies the future for us? ". His answer suggested that some of those will survive, be applicable, but the industry would try different elements, test and apply alternative technologies. He ended by imploring the audience to join with him to supporting this motion. Keith sat down and rested his case!

THE ARGUMENT AGAINST

The second speaker, opposing the motion got up to give a different type of presentation. He confessed that he felt a little ungenerous, although conjectured that this was not his usual style.

He started by asking the audience to considering functional performance, can engineers deliver it and what is the cost to build. So under functional performance, do peoples go into those tunnels and enjoy the experience. Is it durable and the operator does not have to spend hours undertaking concrete repairs?

And for the successful delivery, are the designers really certain what they are getting from the tunnel? He posed the question of "are designers confident at what they deliver?"

The speaker put forward that we are in a state of confusion in this industry, that we do not know what we want.

For example review the 1980's to 2006 to date there is a great deal of variation for example lining thickness is contentious, in fact he showed that since the 1980's lining thickness is getting thicker at time passes.

He referred to a book on sprayed concrete by Alun Thomas with an important table with radius / thickness of the lining. This gives a guide. We are getting smarter and there are green sheets.

He then showed a chart of compressive strength plotted against age to demonstrate the ever increasing desire for more early age strength. He also suggested that there was an ever increasing desire for more early age strength, consequences to this, "Robocrete", high levels of cement, medium high quality cement low water content, altered by higher accelerator dosages, better fibres – all adding up to a lot of uncertainty. Are we going down the right track.Rock cracking behind. Need rockbolts. Plastic fibres.Different testing methods. Sped testing fibre shotcrete.

These days we have 7 layers that all need bonding together, and this suggests we need to simplify.

SCL is the total supervision he suggested jest that this encouraged "savage non marking" against a backdrop showing an image of 9 people watching shotcrete being installed.

The second speaker suggested that SCL architectural was similar to marmite – either love it or hate it. He showed a series of images; South America in large caverns shotcrete behind glass plates, in Helsinki shotcrete with painted murals, etc and posed the question "Would that work in Bond Street with that finish?"

The speaker showed a range of images that were suggested to be "very beautiful" and a trim SGI lining array that were said to be used for most stations linings.

It was stated that SGI linings radial are available and can be used on tight geometric shapes for tight tunnel curves. It was also suggested that key advantages that this material was better for openings and simple junctions compared to SCL. The speaker showed various images of the Jubilee Line Extension to demonstrate this point.

Reference was made to other materials that were stated as having the advantage on SCL such as timber and Lightweight forms of GRP.

Following a extended range of good case histories, the second speaker ended

FUTURE PROOF

As scientists push the boundaries of high energy physics, engineers are pushing the boundaries of tunnelling to create the facilities needed to further explore sub atomic particles

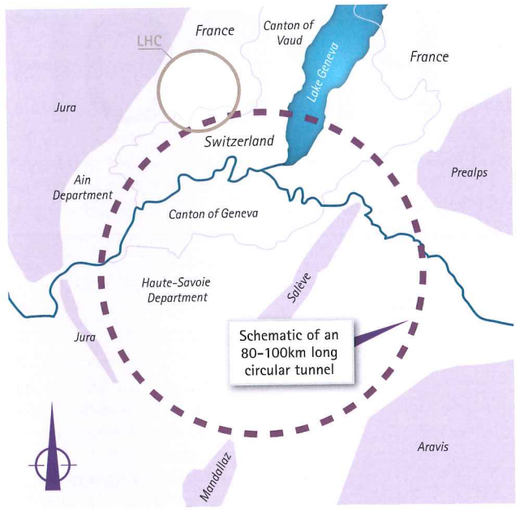
BY THE YEAR 2035 particle physicists are planning to use electromagnets to propel proton beams around a 100km tunnel loop, before smashing them into each other with a 100 teraelectronvolt (TeV) collision energy – enough to release subatomic particles that have never been seen before. Such discoveries, which tell us not only about the world we live in, but about the fundamental elements of the universe itself, can then be used to develop tools and technologies that have not yet even been thought of. "It is in the nature of the human race to understand its surroundings and to ask questions and to find answers. Philosophically it is like art or music, in itself there is beauty in it," explains Michael Benedikt, Future Circular Collider (FCC) study coordinator at European particle physics research facility CERN. "Research and education are fundamental building blocks of our educated society. And it is clear that only by pushing it further we can continue keeping our society moving forward."

Moving forward at CERN has meant a series of collider projects which began with small accelerators and has evolved into larger circular pathways. The most recent development, the creation of the Large Hadron Collider (LHC) which opened in September 2008 was credited with the one of the most important discoveries of particle physics, proof of the Higgs boson particle, a fundamental element of the standard model for atomic physics.

Making this discovery began with a major upgrade to an existing circular accelerator called the Large Electron-Positron Collider (LEP). This 27km ring was completed in 1989 following excavation of 37 caverns, 19 shafts and 32.6km of tunnels. "Here in Geneva we have stable, water tight rock. It

Below: Large Hadron Collider main tunnel
PHOTO: CERN

Bernadette Ballantyne
Bernadette is a regular contributer to *Tunnels and Tunnelling*



is an excellent location for housing tunnels like this," says John Osborne, head of the CERN future projects civil engineering team. The next step for the LHC is an upgrade project named High Luminosity LHC (HL-LHC) which will enable scientists to increase the number of collisions observed in the collider. But this will take ten years to be delivered. "Then the machine will run at high performance for typically another 10 years to 2035-2040 region. By which time it will reach the end of its capabilities," explains Benedikt. "It is clear to the whole community that to carry on researching high energy physics you must be prepared to have something new delivered in 2035-2040, so we are very actively looking at options for that era to continue accelerator based high energy physics at the energy frontier."

***Above:** LHC ring compared with potential future collider*

***Below:** A portion of the Underground Civil Works at one of the LHC 'experimental points'*

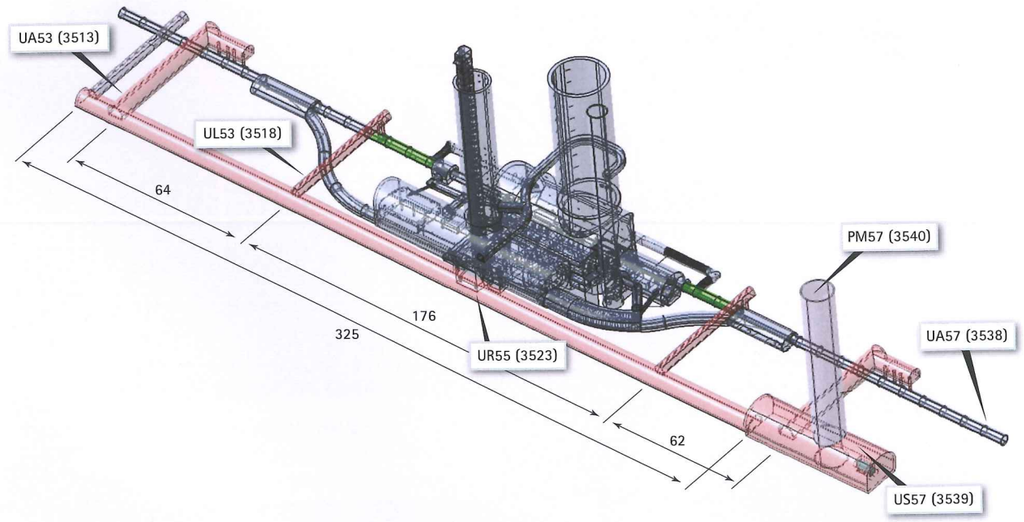
"Something new" could be the Future Circular Collider and to enable scientists to continue to push the boundaries of high energy physics, engineers will need to build it. "For the last few years we have been looking at what is possible from a geological point of view, at reasonable cost and risk," says Osborne, who has been with CERN for nearly 20 years. This conceptual design study will be complete in 2018 in time to update the next European Strategy for Particle Physics in 2019.

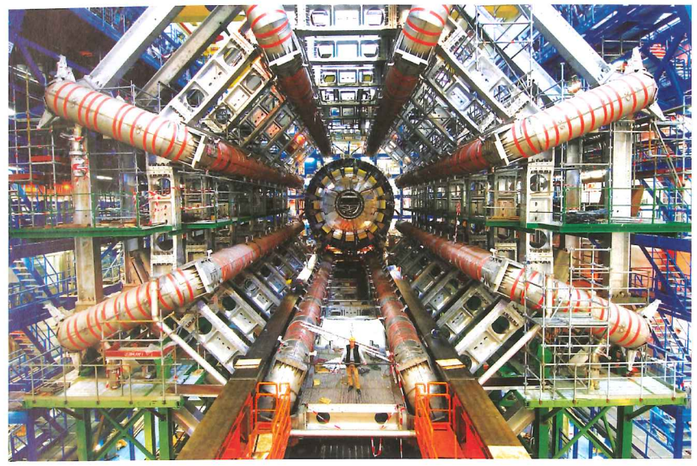
With a circular tunnel length of between 90 and 105km the overall parameters for the scheme make it one of the biggest tunnelling projects in the world. And should CERN opt for a double ring, an option currently being considered, it will become the largest tunnelling scheme ever undertaken dwarfing the 152km of tunnelling for the Gotthard Base Tunnel or the 137km Delaware aqueduct water supply tunnel.

With the size of the accelerator being so huge, engineers had to start by looking at where it could fit. "We approached it purely from a feasibility perspective," says Charlie Cook, a civil engineer at CERN. "The main task at the beginning of the study was looking at the best position for a range of tunnel circumferences. Simply what could we fit in this region and what would be the best position for each site of the collider? We looked at circumferences from 80-100km and that was given as an input from the physicists - who ideally want 100km."

Scaling up

But why does the collider need to be so large? It comes down to the required collision energy. The purpose of particle accelerators is to increase this energy such that the impact between electrons or protons releases subatomic particles. The greater the energy the greater the force of the collision and the more likelihood there is of seeing smaller particles, enabling physicists to identify the fundamental elements of matter – and antimatter. For future research physicists are seeking to create collision energies of 100TeV, over 7 times the current energy level in the LHC. Achieving this requires a combination





***Above:** The Atlas calorimeter, which is used to detect energy levels*
PHOTO: CERN

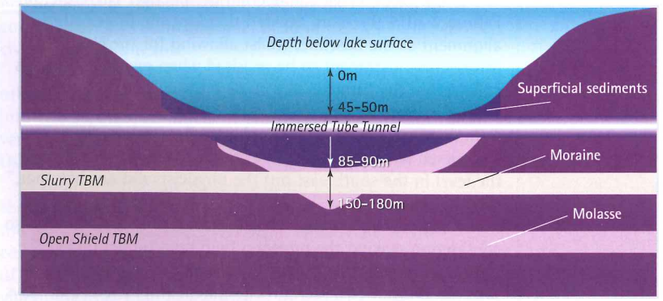
***Below:** Lake crossing tunnelling considerations*

of greater tunnel length and greater magnet power. Even at 100km the physicists must also double the power of the magnets used today. "This requires significant advances directly in this industry and many domains starting with the performance of the wire that builds the coil of the magnets," says Benedikt noting that industrial production capabilities to build it must develop alongside.

For the engineers then development of a 100km tunnel is at the top of the agenda. Although other lengths have not been ruled out development and optioneering is focussed on the 100km tunnel. And previous tunnelling experience in the area has taught the team that locating it in the molasse rather than the more shallow moraines or more challenging limestone is the preferred tunnelling medium. "We have tried to maximise the amount of FCC in the molasse and minimise the amount in the limestone because in this region the limestone is heavily karsified and the fractures filled with muddy watery materials which caused a lot of problems when they were building the LEP tunnel," explains Cook. The Molasse with its mixture of sandstones, marls and formations is dry and stable and considered a good excavation rock although there is some structural instability anticipated. "It is quite nice tunnelling rock, fairly stable and impermeable," adds Osborne.

But given the size of the tunnel and the topography of the region with its mountainous terrain some limestone excavation seems inevitable. CERN is surrounded with the Jura Mountains to the west, the pre Alps on the east and south east, and the Saleve in the middle of the FCC, south east of CERN. Unlike the rest of the tunnel which will use TBMs the team envisage drill and blast for any tunnelling required in these sections.

One of the defining parameters of the new tunnel is that it must be able to connect with the Large Hadron Collider which will act as a pre-accelerator for the beams. This makes passing beneath Lake Geneva another inevitability. As the lake heads northwards its depth increases (see bathymetry diagram). "Wherever we crossed the lake had a knock on effect for the depth of the whole ring. We had to try and keep it as far south as possible essentially to keep it as shallow as we could. We considered other options other than staying in the molasse below the lake so depending on tunnelling technology we could go up into the moraine or even higher into the superficial sediments using immersed tube tunnel technology. But for simplicity of the study at this stage we are opting to stay in the Molasse," says Cook. This means passing beneath the lake at around 200m below the water level. "Going higher means more tunnelling risk but you do reduce the shaft depth," adds Osborne noting that this is something that the team could revisit in the future.



Something else which will certainly be revisited, and is already being used elsewhere, is a bespoke tunnel optimisation tool (TOT) that the CERN team developed in collaboration with consultant Arup. "The tool contains a 3D model of the geology that we put together using various datasets including some data that we purchased from the French Geological Society," says Cook explaining that engineers can change the depth, machine size and location of the tunnel and then examine the implications in the model. "Every time you make a change the outputs tell you the shaft depths, the geology at that profile that the tunnel is running through for each option. It has been a very useful tool for us to immediately get feedback on the impact of changes to the FCC and it has allowed us to narrow and determine the best positions very quickly."

The current concept has 16 shafts which are a combination of 12m diameter access shafts, and larger shafts required for the detection and experimental equipment. "Some of the shaft sizes are ridiculously large. We are seeing up to 31m in diameter and 400m deep so that is pretty big," says Osborne.

To date CERN has always opted for vertical shafts but the challenging parameters have led the team to instead consider inclined tunnels to reach the deepest experimental caverns. "On the

Large Hadron Collider we had quite a few construction difficulties with the shafts. We used ground freezing because we had glacial deposits with water so we basically drilled freeze pipes down to the rock. However we had a lot of water ingress and had to inject liquid nitrogen for weeks on end. So we are looking at alternative methods for shaft construction if we need to go through the water bearing glacial deposits."

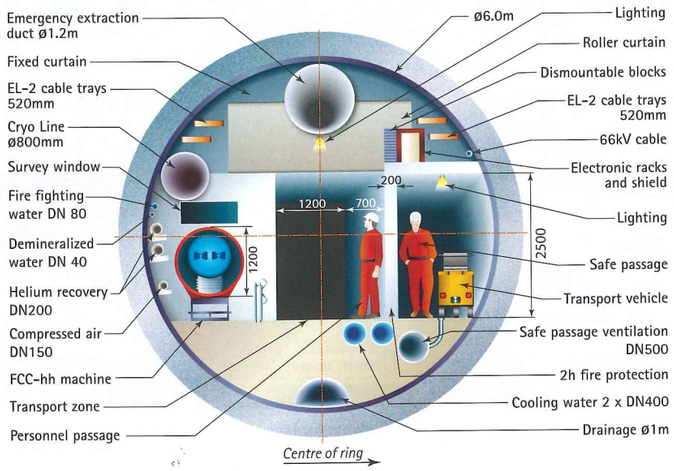
Construction options being considered for the shafts vary according to the ground conditions. They include conventional excavation in the shallow levels of moraines, where lattice girder rings with shotcrete and steel mesh as support will be used in cohesive ground. For looser or saturated ground piles walls up to 25m or diaphragm walls at greater depths are the likely methods. As the shafts get deeper into the molasses, excavation with hydraulic hammers is recommended. However the team are also considering the use of the newly developed vertical boring machines which are likely to have been more extensively used by the time the project begins construction.

To intersect or not to intersect

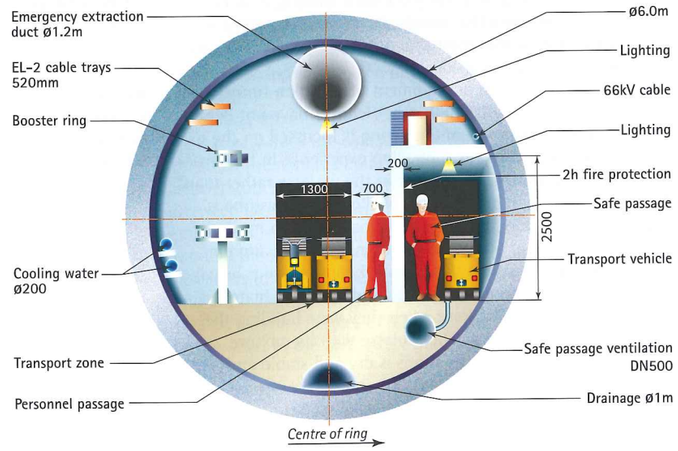
Another consideration for the 100km loop is whether or not it will intersect in plan with the LHC. Some form of connection between the two is a vital element of the scheme, so the team must evaluate whether or not the paths of the two colliders should cross. "You need a series of accelerators to pre-accelerate your beam. It is like when you have a car that you want to drive at very high speeds - you need a gearbox and you start at the beginning with the first gear and then switch from one to the next and have more and more energy. It was always an important part of CERN that it used existing chains as injection machines. The new concept means using existing chain and it is a question of geological optimisation as to how the machines will be linked," says Benedikt.

Having already modelled both an interesting and non intersecting option in the TOT the team have discovered that the optimum intersecting option involves 13.5 per cent of the excavation in limestone and a total 3,211m of shafts, the deepest being 392m. The maximum overburden is 650m and the tunnel passes through the potentially problematic Jura limestone. The proposed non-Intersecting loop avoids the Jura limestone and involves just 4.4 per cent limestone construction but there is a 1,350m overburden in the pre-alps and there is also over 3,000m of shafts required, the deepest being 383m.

FCC-hh possible tunnel cross section: Single tunnel sections



FCC-ee possible tunnel cross section: ARCS, twin diopole sections

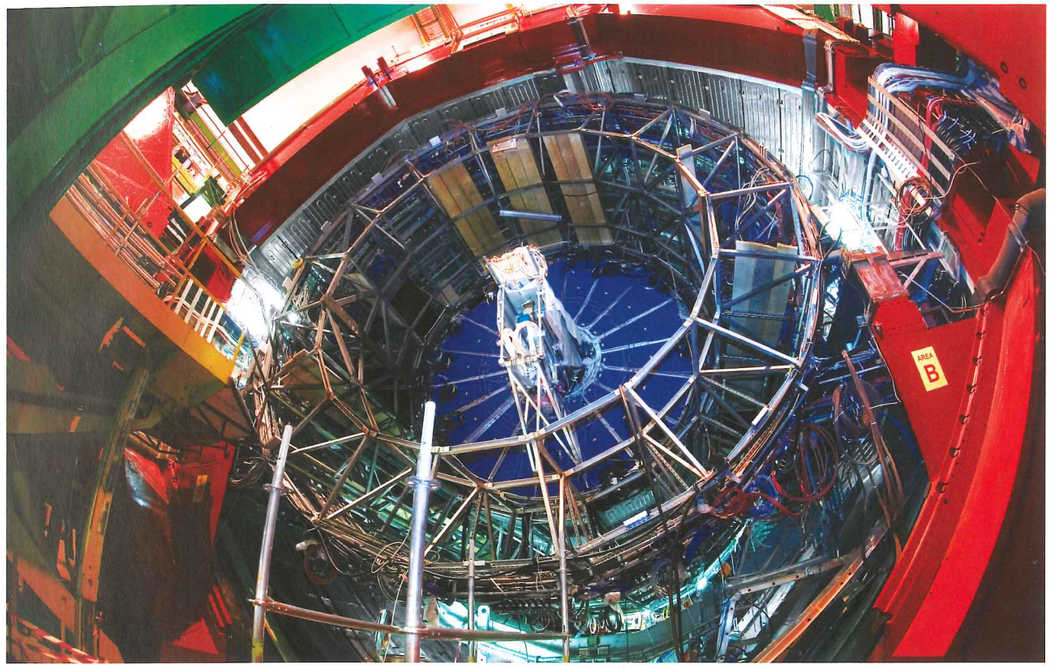


Above: Potential tunnel cross sections

Without any physical data for the geology in the Prealps region, a comparison between the two options could rely only on geological interpretations created by the local geologists, GADZ. However, a study by engineering consultants, Amberg concluded that the Intersecting option appeared the most favourable from a civil engineering perspective. Therefore, in February 2016 the team decided to adopt the Intersecting alignment as the baseline, whilst allowing for the Non-Intersecting alignment to be revisited when geological data is collected in the future.

The concept design also shows the tunnel moving in a single plane, described by Cook as a flat Frisbee. "We considered having some kinks in the machine to try and raise the level in the south east but the physicists did not like that," he says.

To add yet more complexity to the scheme, the team is also considering making the project a twin bore tunnel taking the total length to a record breaking 200km. "It is a question of safety and distance of certain equipment from the beam," says Benedikt. "It really needs a detailed understanding of many



different domains but it will be considered in the next few years."

As the engineers reach the end of the concept design phase they must also produce a preliminary costing for the scheme. "It is too early to say how it will be financed but it would be a global effort. The LHC had contributions from non member states and I would see that in the next phase of technical design we need to think about potential contributions from different regions worldwide," says Benedikt.

CONTRACTORS WANTED

Contractors are currently being invited to prequalify for the tunnelling and shaft construction works of the upgrade of CERN's Large Hadron Collider, the HL-LHC. The project involves two major construction contracts in two locations. Each will involve excavation of a new 300m long underground gallery (at CERN it is typical to reserve the term 'tunnel' for the actual beam tunnel), a service cavern and four cross passages and a 12m diameter access shaft at a depth of 100m alongside the existing 27km tunnel ring.

"We are procuring consultants for design and site management at the moment and we are also looking for contractors," says John Osborne, head of CERN's future projects civil engineering team.

The location of the two sites, with one in France and the other in Switzerland is behind the decision to split the work into two separate contracts. "Even though the packages are very similar you have to respect the local legislation," says Osborne.

A total of 9 bids are currently being assessed for the consultancy work for award in June. Tendering for the construction packages will begin in early 2017. The construction schedule is determined by the planned shutdown of the collider in 2019. The nature of the works, with induced vibrations from road headers likely to impact on the beam, means that the collider must not be operational when the tunnelling activities get underway. "The LHC is very sensitive; it has detected earthquakes all over the world. There is a risk of the vibration impact disrupting the beam so although we can build the shaft when the machine is running the tunnelling must be carried out during the shutdown," says Osborne. Shaft construction is scheduled to get underway in 2018.

Above: The Alice Time Projection Chamber, which studies particle types in the collision fireball
PHOTO: CERN

The Large Hadron Collider began operations in 2008 and has been credited with enabling physicists to prove the existence of the Higgs boson particle, a fundamental element of the standard model for atomic physics. The next step for the circular accelerator is the high luminosity upgrade which will increase the density of particles moving around the ring which in turn increases the number of collisions happening in the collider. The density increase is also described as an increase in the luminosity of the beam giving the project its title as the High Luminosity Project. "The LHC upgrade will take around 10 years until 2025. Then the machine will run at high performance for typically another 10 years to 2035-2040 region. By which time it will reach the end of its capabilities," explains Michael Benedikt FCC study coordinator at Cern. At this point the physicists will continue their cutting edge research using the planned Future Circular Collider, which is currently under development

ACHIEVEMENTS AND ASPIRATIONS

Last month saw a changing of the guard at the *BTS*, with Roger Bridge handing the Chairman's baton over to Mark Leggett. They spoke to **Sally Spencer** about achievements thus far and plans for the future

Sally Spencer
Sally joined the Tunnels and Tunnelling team as a contributing editor last year

IF OUTGOING BRITISH TUNNELLING SOCIETY Chairman Roger Bridge has one piece of advice for his successor, Mark Leggett, who picked up the baton in May, it is "free up your diary".

"The role of BTS Chairman is almost a full-time job," said Bridge, who is tunnelling manager at Balfour Beatty Civil Engineering. "And with the increase in the amount of tunnelling in the UK there is even more to the role and a greater reason for engagement."

That engagement has involved working more closely with other learned societies and organisations and also, perhaps more crucially, with clients. And whereas 25 years ago these tended to be individuals, now "larger, much more coherent client bodies", such as TfL (Transport for London), Crossrail, Tideway and HS2 are more prevalent.

Client engagement has been a major, but not exclusive demand on the Chairman's time. Attention has also continued to be focused on training and education, BTS membership, registration, updating guidance documents and the pitch to host the 2019 ITA World Tunnel Congress in London. In this latter respect the BTS has been unsuccessful, with Naples in Italy being announced as the 2019 host during this year's event in San Francisco.

"We were obviously disappointed with this result" said Leggett, but added "we wish Naples and the Italian Tunnelling Society every success in running WTC 2019; we still believe that the UK and London would be a fantastic venue for WTC and no doubt we will look for future opportunities to do so."

In the meantime, work goes on the home front.

"I've always been very keen on training so my goal during my tenure as Chairman was to progress with that and improve the popularity of our Design & Construction and Underground Health & Safety courses," said Bridge, adding that uptake of these is now at an all-time high.

"I also work with TunnelSkills as an offshoot of the BTS and we have identified an absence of an underground survey training capability, so we are developing one, initially for technicians, which will be jointly delivered by TunnelSkills and the Tunnelling and Underground Construction Academy [TUCA]."

Bridge has also worked to increase membership numbers, some of which has involved tightening up on the 'housekeeping' but much of which has centred on explaining the benefits of membership, particularly to corporate members. At the top of the list of these benefits is enhanced client engagement.

The membership drive has been successful and figures now stand at more than 800 individual and 78 corporate members – another all-time high.

Roger Bridge

Mark Leggett

Other tasks have included continuing the good works started by former chairmen, such as establishing a registration scheme for tunnellers – as distinct from civil engineers.

"Unlike the Institution of Civil Engineers [of which the BTS is an Associated Society], which is very much aimed at the professional engineers with chartered status, the BTS is an all-inclusive society," said Bridge. "We welcome suppliers and operatives as well as engineers as members because we recognise they all have something to contribute.

"However, as the number of projects rises, clients are increasingly looking for certainty and confidence that operatives have the necessary tunnelling experience and expertise, so we've been looking at a registration scheme.

"The Register of Ground Engineering Professionals (ROGEP) is already out there but it's for professionals and excludes some of our membership, so we've been working with them and they are looking at expanding the ROGEP scheme to include all levels of tunnellers.

"It's much better for us to have a system we can tie into, rather than set up our own," said Bridge. "We haven't got as far as we would have hoped but we are certainly a lot further forward."

He added that the BTS has also worked with some of the chartered institutes, such as ICE and IOM3 (the Institute of Materials, Minerals and Mining) on developing NVQ Grade 3 holders through the EngTech route in order to bring them through the registration process.

As well as collaborating with ROGEP and the aforementioned TunnelSkills and TUCA, the BTS has also had more engagement with the ICE over the last two or three years and also with the International Tunnelling and Underground Space Association (ITA).

"Whereas in the past an Associated Society just co-existed, the ICE now demands more contribution and input from us for their own offering and knowledge sharing. Our experience of running courses and conferences has led to more interface with the ICE."

Interest in the ITA has also grown, particularly as the creation of the BTS Young Members group (BTSYM) seven years ago has been instrumental in the establishment of the ITA Young Members group and similar bodies across the world.

"There is a lot of interaction between the ITAYM and the BTSYM, which is involved in many of the working groups," said Bridge.

Above: The BTS holds monthly evening lectures at the Institution of Civil Engineers in London

And, of course, there has been another imperative for the link with ITA, which was the BTS's bid to host the 2019 World Tunnel Congress.

"The BTS has always had a good input into the worldwide tunnelling sector – our guidance on working with compressed air has become the default document in many countries, for example – but hosting the WTC would have increased our exposure and let the rest of the world know what the UK market is like," said Bridge.

Another benefit would have been the funds the event would have brought into the BTS, which could be used, for example, to develop more guidance documents and/or provide bursaries for the Tunnelling and Underground Works MSc at Warwick University.

New chairman Mark Leggett, who is divisional director of Mott MacDonald's Metros & Civil Division, says hosting the WTC would have been "a long overdue showcasing of British talent" and that there is an abundance of projects that would have been under way by 2019 to present to the tunnelling cognoscenti.

These include HS2 (Leggett is currently leading the Mott MacDonald HS2 London Metropolitan hybrid Bill team), Thames Tideway, Silvertown, York Potash and, potentially, Stonehenge and Crossrail 2, as well as numerous underground station upgrades. There is also a myriad of smaller diameter tunnels, including flood attenuation works, pipejacks for water authorities and work for the National Grid, the latter including 32km of tunnelling in London.

A large amount of work is being dished out, and companies are filling their boots. Notably the Thames Tideway contracts were recently issued, with the East Section being designed by Mott MacDonald for a joint venture of Costain, Vinci and Bachy Soletanche. The West Section is being designed by a design JV of Arup and Atkins for Bam Nuttall, Morgan Sindall and Balfour Beatty. The central section will be designed by Aecom for a JV of Ferrovial Agroman UK and Laing O'Rourke.

Bridge and Leggett agree that in their respective 28 and 25 years of working in the tunnelling industry the market has never been as buoyant and the number of major, or 'glory' projects has never been so high.

Neither has the wider awareness of the benefits that tunnelling can bring. Bridge recalls a meeting at the Major Projects Association recently where presentations – including one on a film studio development in east London – all led to conversations about tunnels and how they would facilitate access.

Tunnels are now also seen as vital components of other major infrastructure developments. The UK government is keen to harness the "northern powerhouse" and projects such as HS2, HS2 phase 2 and the Trans-Pennine road tunnel [running under the Peak District and connecting Sheffield and Manchester] are all key in permitting this.

Government aside, the British public is also increasingly conscious of how tunnels can improve their quality of life. The BBC's three-part documentary on Crossrail played its part in raising awareness by metaphorically taking the public underground and demonstrating the process and highlighting the improvements to transport links.

Above: Inside the Institution of Civil Engineers

It's the type of communication Leggett would like to see much more of.

"It's time we started to use technology to bring what is happening underground on our big projects to the general populace – we could do it on the web," he said.

"We revamped our own website a couple of years ago and it's a really good source of information now," he said. "We've recognised that the world has become more digital so we are looking at the different forms of communicating our message and how we should engage with social media such as Twitter."

Leggett believes the BTSYM has an important role to play here.

"Younger people are so technologically connected – their information comes and goes in a different way. And they are much more alive to social issues and resilience than we ever were and they have so much access to instant information, which they pass between them. We can learn a

lot from them."

In fact, Leggett is keen to harness the energy and enthusiasm of the BTSYM and use it "to the best endeavour".

One BTSYM initiative he is eager to pick up on during his chairmanship is the Teacher's Pack – a series of 10 lessons, comprising presentations, guides and practical worksheets, for delivery to 11-14 year-old schoolchildren.

"They've been tested a couple of times in schools and there has been some teacher involvement but we haven't worked out how to roll it out yet," said Leggett. "Even the Science, Technology, Engineering and Mathematics Network (STEMNET) says it's difficult to get [teaching aids] into schools, but we've got to get those Teacher's Packs out and I'm hoping we can get STEMNET and the ICE to help with that.

"We educate the industry with our own BTS courses – and I hope we can also offer some more commercial/ insurance type courses and training events, perhaps jointly with the ICE and industry. We also have links with TunnelSkills, TUCA and the MSc course at Warwick but the schools thread is very important.

"Engineering UK has predicted that with the volume of work we will have an annual shortage of 69,000 technicians and engineers across all sectors," said Leggett, adding that peoples' career choices were often made when still at school and that if tunnelling-specific training and education didn't kick in until postgraduate level, many will follow other paths.

He's hoping, too, of course, that further education will gain momentum.

"Warwick University's Tunnelling and Underground Works MSc is a unique course, both by virtue of the amount of support and input from industry and also the fact that the BTS chairs the steering group," said Leggett. "It's the jewel in the crown for the BTS, and I would like to see more students entering the course each year, more employers providing bursaries and a bigger uptake from industry of the taught modules."

This year will be one of change as the principal teaching fellow Benoit Jones has moved on (to the University of Cambridge) and is succeeded this summer by Alan Bloodworth, formerly a lecturer in civil engineering at the University of Southampton. His stated research interests are in tunnelling, soil-structure interaction, reinforced concrete structures and the use of fibre reinforced polymers in construction.

"Benoit did a fantastic job and we can now build on that legacy," said Leggett. "I'm hugely excited by that and believe that, together with Warwick, we can really grow the numbers on the course and grow demand from industry. We want more people in this industry – particularly clients – to recognise its importance.

He added that some clients, such as HS2, are opening or sponsoring colleges, so care had to be taken to collaborate rather than duplicate effort.

Leggett is also keen to continue Bridge's efforts to make the BTS "less London-centric" with the revival of regional meetings. The first of these was held in Glasgow last year and was aligned with the 5km-long Shieldhall wastewater tunnel for Scottish Water. The plan is to pick up on other projects outside London and run similar regional meetings. A candidate for this is the York Potash project, which got the go-ahead last summer and which will see a new potash mine established under the North York Moors National Park. The minehead will lie between Whitby and Scarborough and tunnels extending about 16km inland from the coast and up to 14km offshore will mitigate the impact on the environment.

These regional meetings will reflect the "shift in dynamic", said Leggett. "This includes HS2, which itself is setting up in Birmingham. There is some significant tunnelling planned in that area in the future – we have to link with the northern powerhouse."

Leggett will also continue to articulate the benefits of BTS membership and the range of capability afforded by having both individual and corporate members. "We need members to know what they are getting so we will continue to develop the benefits of the different memberships so that it is clearer and more tailored to each category," he said. "And we have more clients joining the society now so I'm thinking about whether we should have a client or owner membership category."

Having fed into the government's 2010 National Infrastructure Plan the BTS now has a role in the All-Party Parliamentary Group on Infrastructure and Leggett would like to see strengthened support for this and greater involvement.

"The link we have with government is hugely important," he said. "We received strong support from the government for our bid for WTC 2019 and I believe that the UK government now really understands and accepts the place that use of underground space has in society and for the development of our infrastructure. After all, London's success was built on the Tube.

"We want all parliamentarians to see the use of underground space as an option that offers great value and delivers huge benefits."

"We are moving into a time where we're not just talking about tunnels but about urbanisation underground and putting a lot of traditional surface facilities underground," continued Bridge. "In Hong Kong they are starting to put water treatment facilities underground and, in Europe, some sports halls and event arenas have been moved underground. There is also the concept of residential and office 'earthscrapers'. There's a lot to be done and we're only just starting."

He added that this is an area where the BTS are working closely with Think Deep UK and the ITA Committee on Underground Space (ITACUS) to promote the informed and efficient use of underground space.

Bridge and Leggett are united in their view that the future is looking bright for tunnelling in the UK and, by extension, for the BTS. "Already there is at least 20 years of tunnelling ahead and there will be more projects following that, too," said Leggett. "I am confident about the future – more so than ever – because using underground space is proving its value and the case for tunnelling has never been stronger"

UNDERGROUND INNOVATION

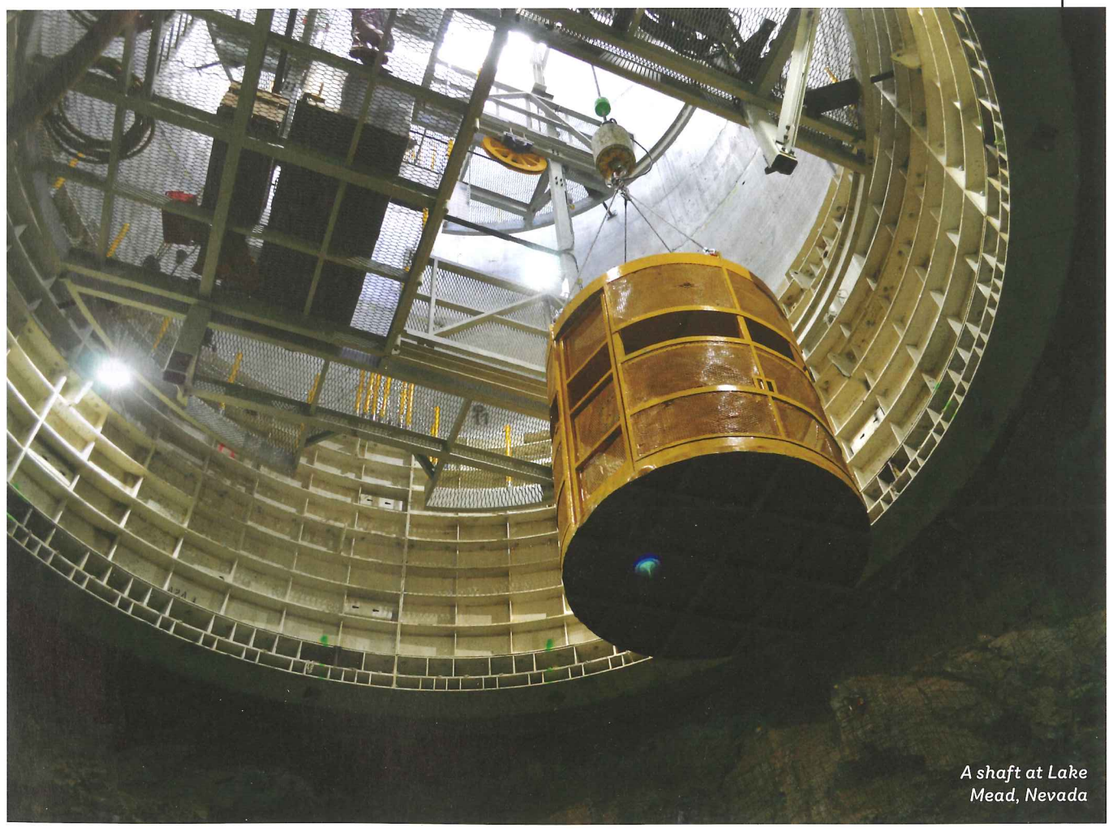
Erika Moonin
Erika is an engineering project manager for the Southern Nevada Water Authority

THOSE WHO reside east of the Mississippi River driving west for the first time are often struck by the dramatic change in landscape as they motor along. Most travellers enter the desert southwest states of New Mexico, Utah, Arizona or Nevada after passing through hundreds of rain-blessed miles of green vegetation, rivers, and lakes.

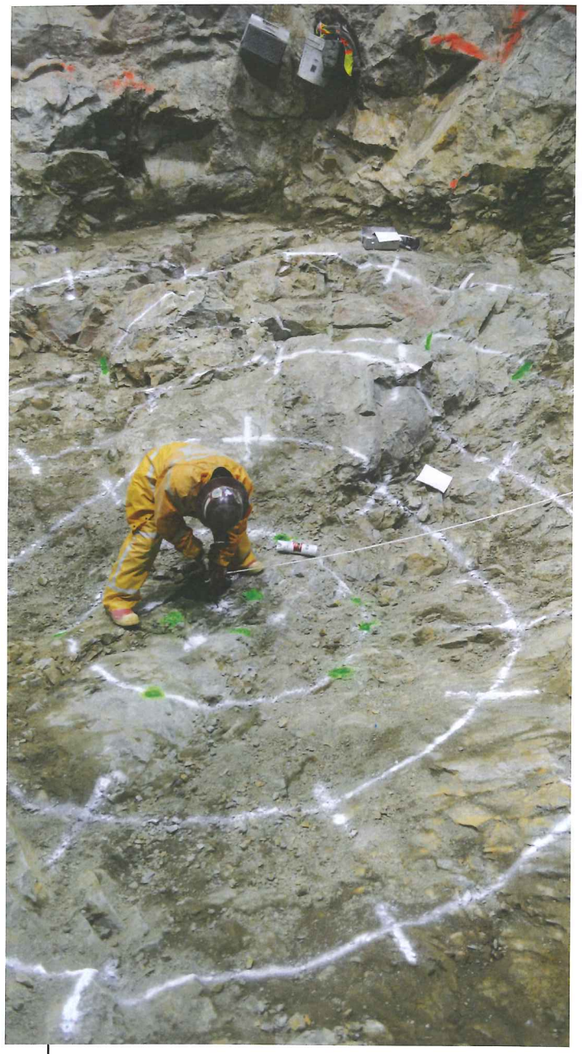
Following the setting sun west, bountiful waters become scarce and the land becomes more barren. The lack of verdant landscapes is unmistakably reflected in a stark terrestrial transformation caused by the West's naturally dry climate. Many visitors have struggled to see the beauty of the desert regions, but many others have found the raw exposure of the land to have a more sublime beauty and have been willing to adjust living practices and conserve the limited water resources in order to enjoy the benefits of living in the arid West.

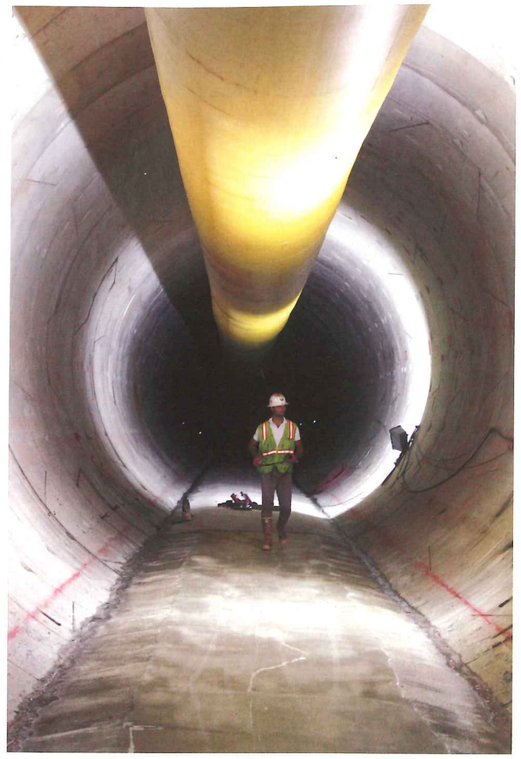
Make no mistake; there are many water resources in the West, but compared to the East, water in the West is much more scarce and becoming more so, and that means communities need to make some difficult decisions.

Southern Nevada is already dealing with the issues of water scarcity and is investing in underground infrastructure to prepare for the future. **Erika Moonin** engineering project manager with the Southern Nevada Water Authority explains the capital improvement projects underway at Lake Mead



A shaft at Lake Mead, Nevada





ANSWERING THE NEED

At first glance, Lake Mead, just on the outskirts of Las Vegas, appears to be the picture of water abundance. The 248-square-mile (642-sqaure-km) body of water is the nation's largest man-made reservoir capable of storing more than 28 million acre-feet (about 9 trillion gallons or 34 trillion litres) of water, which is used to satisfy the thirst of municipal and agricultural water users in Arizona, California, Nevada and Mexico. In fact, every drop of water in Lake Mead is highly regulated, each gallon allotted and every stored acre-foot bagged and tagged to meet water demands all the way to Mexico.

More than 40 million people depend on the Colorado River, which flows into Lake Mead; however, severe drought conditions over the past 16 years have significantly reduced the river's flows and decreased Lake Mead's water levels. In response to the drought, water managers throughout the desert southwest are implementing progressive actions to maintain sustainable balances between water supplies and water demands.

*Above: **Workers at the various sites for Lake Mead's Intake No. 3 project.***

Few water wholesalers have had to face as many drought-driven challenges as the Southern Nevada Water Authority (SNWA). In a community that receives only four inches of rain per year, Southern Nevada relies upon Lake Mead for 90 per cent of its water supply. Ensuring reliable drinking water for two million residents and more than 40 million annual visitors, SNWA employs a comprehensive 50-year water resource plan that balances water supplies with the region's current and future water demands. While drought conditions heavily influence water resource planning efforts, capital investment in new underground water infrastructure is helping secure the community's access to its critical water supplies in Lake Mead.

AN UNDERGROUND SOLUTION

Long-term forecasts for Lake Mead raised enough concern about the future operability of SNWA's existing intake system that the board of directors in 2005 directed staff to design and construct a third water intake, and more recently, a new pumping station capable of pumping water from extremely low lake levels.

The primary objective for the Lake Mead Intake No. 3 project was to maintain access to Southern Nevada's existing water supply should the lake level continue to decline. It's not about investing in infrastructure to get more water – it's about investing just to protect access to the existing supply.

Through forward-thinking leadership and an abundance of planning, engineering and construction ingenuity, the solution to securing access to Southern Nevada's Lake Mead water supplies was found deep underground, and deep underneath Lake Mead. By the time sustained drought-conditions reduced Lake Mead's storage to 43 per cent of its capacity in 2009, SNWA had already begun construction on the Lake Mead Intake No. 3 project – the most ambitious project and single largest public works contract ever undertaken by SNWA.

The main components of the project include an intake structure and underground tunnel that draws and conveys water from a deeper location in the lake. Even if the lake drops too low for water to pass through Hoover Dam to meet downstream water demands, Southern Nevada will still have access via the new intake. The project's earlier contracts also include a connecting tunnel from the new intake to the SNWA's existing intake system, as well as a number of underground connections and modifications to accommodate the flow of water from Intake No. 3 to existing intake pumping stations.

Though supported by a large above-ground presence, the heartbeat of construction for the Intake No. 3 tunnelling project was staged and progressed 600ft (183m) underground. There, contractors drilled and blasted first a 600ft-deep access shaft, then a large cavern where they assembled a 1,600-ton TBM. They then sustained the advancing TBM underneath Lake Mead for several years in challenging geologic conditions and extreme hydrostatic pressure due to the direct underground connectivity to lake water, setting the world record with a sustained operating pressure as high as 15 bar.

The skilled underground crews were reinforced by a robust team of engineers, managers, technicians and construction personnel who worked as a team to complete 3 miles (4.8km) of 20ft (6m)-diameter segmental-lined tunnel underneath the lake to connect to an awaiting 100ft (30m)-tall intake structure. The intake structure, constructed concurrently with the tunnel excavation, took nearly five years to design, construct and secure to the bottom of Lake Mead using nearly 12,000 cubic yards of tremie concrete. Work on the intake structure was completed in March 2012.

The new intake facilities were designed to convey 900 million gallons (3.4 billion litres) of water per day. Since its commissioning in September 2015, billions of gallons of water have already flowed through the intake system's series of tunnels, underground caverns, shafts and forebays before finally reaching customer taps throughout the valley.

LOW LEVELS

By December 2014, with Intake No. 3 nearing completion, drought conditions in the Colorado River Basin were persisting, causing record low water levels since the filling of Lake Mead after the construction of Hoover Dam.

Projections for Lake Mead's elevation indicated continuing declines in lake levels, absent significant relief from the drought, putting the operability of both of SNWA's existing intake pumping stations in jeopardy.

The pursuit of a third pumping station, an original but deferred component of the Lake Mead Intake No. 3 project, was quickly sanctioned by the board of directors. Both the board and a citizen advisory committee strongly recommended the new pumping station be developed in the swiftest feasible timeframe in order to keep ahead of a dropping lake.

The aptly named new Low Lake Level Pumping Station (L3PS) will replace the capacity of the current intake pumping facilities and operate at very low lake levels.

Once again, planners and engineers looked underground for the solution. The new pumping station includes a 525ft (160m) deep, 20ft (6m) diameter vertical shaft, an underground forebay tunnel and connection, and 34 deep well shafts for submersible pumps.

The contractor and the SNWA have formed an alliance under a Construction Manager at-Risk contract approved by the board of directors in May 2015.

The L3PS team, comprised of SNWA project representatives, consulting engineers, and the Construction Manager at-Risk and the program management firm, is engineering the project to include design features that are both economical and compatible with efficient construction methods. Construction of the pumping station is under way and the project is expected to reach completion in 2020.

CONCLUSION

At a time when drought and water scarcity are increasingly affecting communities worldwide, Lake Mead Intake No. 3 demonstrates how Southern Nevada has remained ahead of the curve when it comes to the drought and declining water levels in Lake Mead.

Using innovative tunnelling technology and progressive engineering solutions, SNWA has incorporated underground space – including a 3-mile tunnel underneath Lake Mead – to secure a reliable water supply for the long-term future of Southern Nevada.

The cutting edge, innovative use of underground space for the purpose of protecting the community's water supply ensures that water will continue to flow despite the persistent signs of scarcity ringing the shores of Lake Mead

Acknowledgements

SNWA would like to thank the following Lake Mead Intake No. 3 designers, contractors and their crews:

MW/Hill Joint Venture (MWH and CH2M Hill): Owner's Engineer
Parsons Water & Infrastructure: Construction and Program Management
Vegas Tunnel Constructors (Salini Impregilo) and Arup: Shafts and Tunnel Design-Build Team
Renda Pacific: Connector Tunnel
Las Vegas Paving: Intake No. 2 Connection and Modifications and Low Lake Level Pumping Station

FINAL STAGES

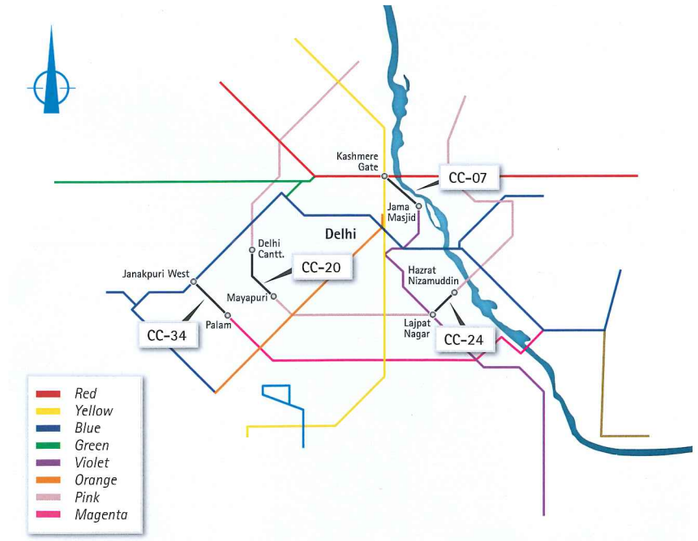
Bernadette Ballantyne
Bernadette is a regular contributer to *Tunnels and Tunnelling*

With 12km of tunnelling completed on phase three of India's most advanced metro project, *Terratec* gives an update from worksites it supplied machines to, as tunnel work enters the final stages

FROM FULL FACES OF QUARTZITE to mixed conditions of soil and hard rock, and the need to avoid the foundations of newly built elevated metro stations, there have been plenty of challenges for the tunnellers working to deliver phase III of Delhi's metro system for the Delhi Metro Railway Company. TBM supplier Terratec has been supporting contractors on four major contract packages and despite the challenging ground, advance rates have been good with breakthroughs being achieved throughout 2014 and 2015.

Contract CC-07 has perhaps been the most challenging for the team led by the main contractor joint venture of Russia's Metrostroy with local firm ERA Infrastructure. The first twin drive between Kashmiri Gate and Lal Quila began in December 2014 and breakthrough was celebrated the following August. "The varied geological profile was the biggest technical challenge," explains Bruce Matheson, regional manager for Terratec. Along this 1.35km drive the mixture of soil and hard rock meant that that the advance rates were variable averaging 20m/d in soil whereas in the rock it was 6m/d. Fortunately the 900kW VFD electric drive mixed ground cutter head for the 6.61m o.d. EPB shield machine was more than capable of handling the quartzite which at one point was dominating the bore. "The full face of hard rock wasn't expected but the machine was perfectly capable of cutting through the rock. It did mean that the contractors ended up eating a lot more cutter discs though," says Matheson. Creating the tunnel took 967 rings, each consisting of five segments plus key.

The second drive to complete the down line which runs from Jama Masjid back to Lal Quila is set for completion in January 2016. Between them the two TBMs will create two critical tunnel sections located to the north of the Violet Line (Line 6) which was built as part of the second phase of Delhi's metro. The existing 20km section began operations in October 2010. Further extensions to this line are also underway as part of phase III.

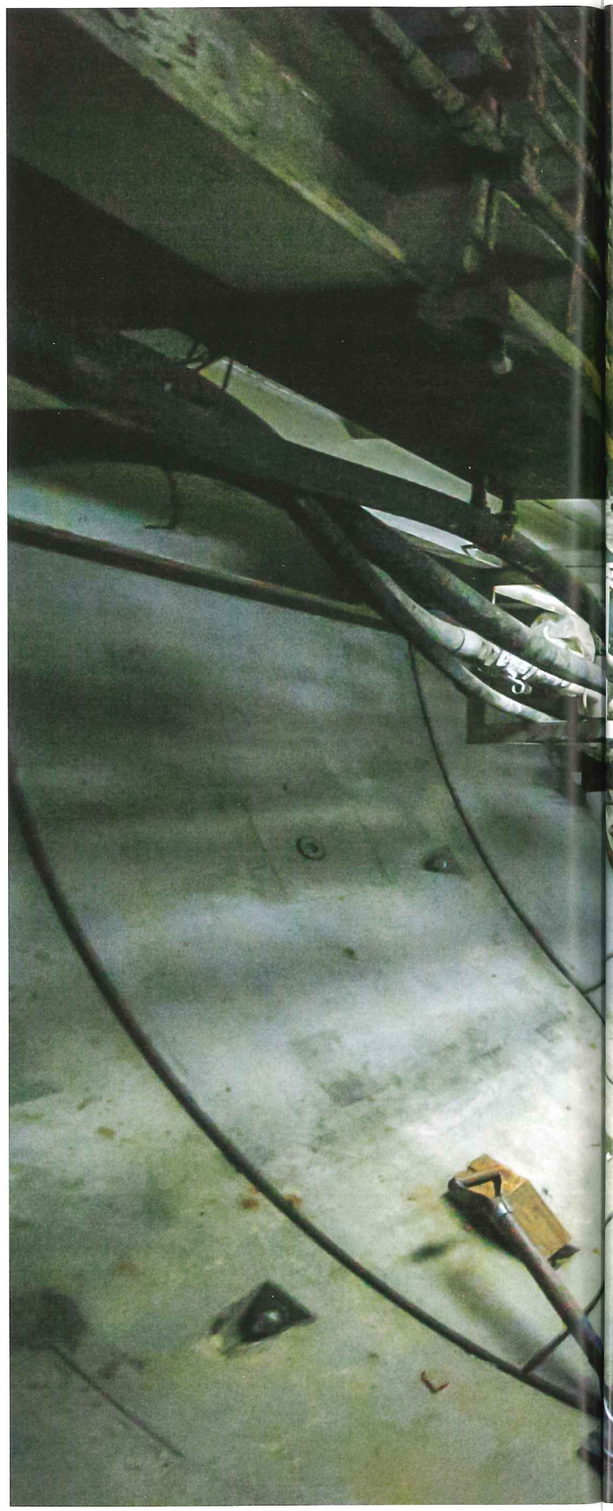


Below: Delhi Metro map showing relevant contracts

Further south Terratec machines have also completed several important bores on the new 58.6km Pink Line which takes a U shaped loop through the city starting at Majlis Park in the northwest, heading south through Mayapuri and Delhi Cantt before heading east through INA to Lajpat Nagar where it then heads north again back up as far as Shiv Vihar. Within this, contract CC-24 has seen Indian contractor J. Kumar & Associates working with China Railway Tunnel Group (CRTG) to deliver 6.9km of new metro tunnels running between Lajpat Nagar and Nizzamudin. Completed in three drives the last 966m section between Vinobapuri and Ashram is set for completion in March 2016. "This was in mixed ground and the ground was as expected so we were advancing at 70mm/min. We were regularly placing 15 to 20 rings per day and it went really well," says Matheson.

Heading west from Lajpat Nagar contract CC-20 will deliver 2.2km of new line between Mayapuri and Delhi Cantt. Very hard rock along the full face of the alignment was expected within this section so advance rates were steady at 12m per day. The low water table allowed the contractor, which was again the J. Kumar & Associates/CRTG joint venture, to change the 17 inch cutters quickly. The final breakthrough on this contract at Mayapuri is scheduled for this February.

The final contract CC-34 to deliver 3.6km of new tunnels is the first to be completed in full. The three drives will enable construction of the Magenta Line (Line 8) which runs east-west across the south of Delhi. Delivered by a joint venture of Hindustan Construction Company (HCC) with South Korea's Samsung Engineering and Construction



Group, the completed section forms part of the most westerly section of the new line between Janakpuri and Palam Station.

Initial boring started in August 2014 from Vikaspuri Shaft and broke through 219m later near Kerala school. From there both TBMs were dragged 110m through the cross-over area to start boring a second drive of 354m to Janakpuri Station. The stretch between Vikaspuri and Janakpuri stations was carried out under moderate water pressure up to 2 bars. Beneath the existing Janakpuri elevated metro station the distance between the tunnel wall and foundation piles of the existing metro station was only 3m. "We had to go carefully and gently and this was really the balancing part of the EBP operation. This was soil and there was no rock in this alignment," says Matheson explaining that overall progress on this

All: Contract CC-20 (right) and CC-07 (above) both had to deal with very hard rock but cutter change was aided by a low water table

Table 1. Delhi Metro Phase III - Lines with Underground Sections

Line	Colour	Underground running length (km)	Overground/ elevated (km)	Total (km)
Line 7	Pink	19.1	39.5	58.6
Line 8	Magenta	23.8	10.5	34.3
Line 6	Violet	9.4	0	9.4
Line 3	Blue	1.5	2.8	4.3
Other overground			52.7	52.7
Total		53.8	105.5	159.3

Source: DMRC

section was excellent.

The geology in this area was composed of very wet silty clay and sandy soil typical of Delhi. Both TBMs passed underneath residential areas for what a very accurate settlement control was implanted, keeping the settlement within less than one centimetre on those critical zones.

During construction of the final section from Dashrathpuri to Palam Station the twin 1,224m long drives passed through very dry soil, and the foam injection system on the TBM cutterhead was used for conditioning of the muck. On this stretch the contractor kept steady advances of up to 120m per week.

The contract drives were completed in August with the second machine S36 finishing a month after its twin S37. The lack of rock meant that these TBMs had a spoke type cutter head with a 57 per cent opening ratio. The good progress was recognised at the breakthrough ceremony. "We are thankful to all our sub-contractors and equipment suppliers, especially Terratec, as these TBMs have excavated very smoothly and this has helped to complete the works ahead the planned schedule" said Mr. Raman Kapil, project director of the joint venture. By early 2016 Terratec's eight machines will all have finished work making their valuable contribution to the 58km of new underground lines that are part of phase III. A further 105km of overground lines are being built too taking the total phase III network to 159km - adding to the 189km of lines already in place. "It was, and is, a very aggressive and ambitious programme which has been carried out very well." summarises Matheson.

DELHI METRO TAKES THE LEAD

Delhi metro has been a pioneering project for India and it is thanks to the drive of the Delhi Metro Railway Corporation (DMRC) that light rail systems are now being constructed in cities throughout the country. The organisation embarked upon the metro in the late 1990s with phase one planned to deliver a 65km system with 13km of this built below ground. Costing USD 1.6bn at today's rate) the system opened in phases with the Red Line, line one being the first to begin some services in December 2002. Other sections of the line opened in 2003 and 2004 and operations on lines two and three followed between 2004 and 2006.

Phase two required a lot more tunnelling with almost 30 percent of the 124km expansion being carried out underground. The simultaneous use of 14 TBMs during 2008 was a high point for the project which saw TBM manufacturer Herrenknecht supply 20 machines over 11 different contracts. Unexpected rock became a feature of the underground work and in one case Herrenknecht explained that it had to deliver a new cutting wheel to the contractor to fit to its machine in order to make it through the rock. Tunnelling was completed in October 2009 in order to ensure that the new lines were open in time for the Commonwealth Games the following year. The cost of this phase was USD 2.8bn.

Today phase three is underway which is set to add almost 160km to the network, almost doubling the 189km that is now operational. Not surprisingly then the cost too is much higher with a budget of USD 6.2bn.

In March this year DMRC announced that there were 19 TBMs working beneath the streets of Delhi constructing the 53km of new tunnels needed to expand the network. At the project peak there were 26

*Below: **Break through on contract CC-34***

FISHER STREET CROSSOVER: CONSTRUCTION OF THE SECONDARY LINING

Engineers working at the Fisher Street Crossrail site analyse the secondary lining installed for a crossover between the two main lines

THE CROSSRAIL ROUTE will run for more than 100km from Reading and Heathrow in the west, through new twin-bore 21km tunnels under central London, to Shenfield and Abbey Wood in the east. Crossrail has the requirement for crossovers, one of which was provided at Fisher Street – a small site between Tottenham Court Road and Farringdon Stations. The crossover will allow trains to switch between eastbound and westbound running tunnels, for maintenance or emergency reasons.

The Fisher Street site is located next to the Holborn London Underground (LU) Station in Central London, and was part of the Crossrail contract C300 - Western Running Tunnels (Royal Oak to Farringdon), awarded to the joint venture of Bam Nuttall, Ferrovial Agroman, and Kier Construction (BFK), in December 2010.

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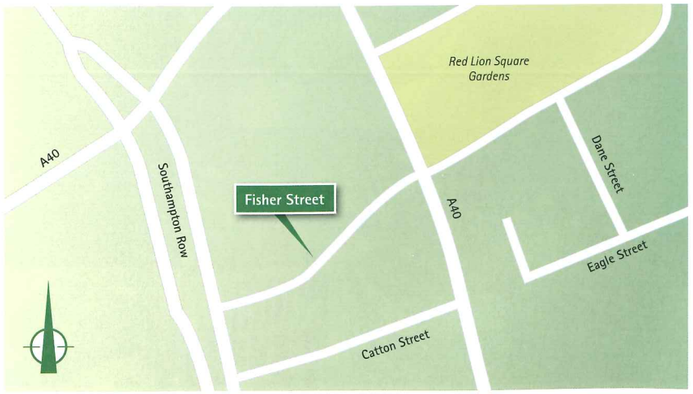
The underground environment in this area is rich in important LU assets. The Piccadilly Line bores are the deepest tunnels in the area followed by those of the Central Line. The Crossrail running tunnels are constructed between the Central Line tunnels and the disused Kingsway Tram Tunnel (KTT). The KTT was initially used for compensation grouting works through a grout shaft, however, it was later decided to use it to overcome the logistic challenges of a small footprint site in central London, resulting in an area for concrete deliveries and materials storage.

Opened in 1906, this tram cut-and-cover tunnel once took passengers from Holborn to Waterloo Bridge, providing a link between the north and south London tram networks. KTT and its double-deck trams were abandoned in 1952, however this unique piece of London's transport history is still fascinating audiences in films, including The Escapist and The Avengers, where it serves as the entrance to a secret underground base.

The location of Fisher Street site in a busy and lively area of Central London meant it had some constraints that limited the type and extent of certain work activities (location shown in Figure 1). The site is bounded by Fisher Street (to its north), Southampton Row (west), Catton Street (south) and by a UK Power Networks (UKPN) building to its east. Fisher Street was closed to its western end to accommodate the BFK worksite.



Below: ***Figure 1, The location of Fisher Street in Soho, Central London***

Catton Street was closed for non-Crossrail construction works. Access for lorries and deliveries was restricted to the eastern entrance through Fisher Street. Besides the physical barriers, some construction activities that generate ground borne noise and vibration were also subjected to time restrictions due to the local residents in the vicinity.

Construction began after the running tunnels were excavated by two EPBMs and included the realisation of the following structures:

- An access / intervention shaft;
- Two intervention adits (IA1 and IA2) to connect the shaft to the running tunnels;
- Two tunnel enlargements (caverns) – one in the eastbound (EBX) and other in the westbound (WBX) route;
- A crossover tunnel connecting the two caverns;
- Two cross-passages - each connecting to the running tunnel and crossover tunnel;
- Two niches in the crossover – storage areas.

The intervention or access shaft is located behind a Grade-II listed building, at 8-10 Southampton Row, where oversite development will follow once the main Crossrail works are completed.

UNDERGROUND WORKS

The tunnelling works undertaken at Fisher Street involved the use of different liners:

- The intervention shaft, 30m deep by 15m diameter, constructed using 10m deep secant piles followed by excavation and primary Sprayed Concrete Lining (SCL) to the base level and completing the shaft with sheet waterproofing and cast-in-situ secondary lining works;
- Crossover tunnel, 45m² cross section by 59m long, constructed using SCL for the primary lining and cast-in-situ concrete, for the secondary lining;
- Eastbound and westbound tunnel enlargements, cross sections vary between 60 and 140m² by 56m long, constructed using sprayed concrete lining for both, primary and secondary lining.

The simplified local geology consisted of Made Ground and River Terrace Deposits, from the surface level to 8m deep, followed by an 18m stratum of London Clay, 11m of Lambeth Group, 11m of Thanet Sand Formation, and Chalk Group at the bottom. The bottoms of the caverns were excavated within the Lambeth Group, with the tunnel crown in the London Clay with a proportion of 25 per cent and 75 per cent respectively.

DESIGN AND SPECIFICATIONS

Traditional methods of building tunnels in soft ground typically demanded the construction of a double lining structure, referred to as the primary and the secondary lining (with sheet waterproof membrane in between), of which Fisher Street Intervention Shaft is an example. With modern improvements in sprayed waterproofing technology, and understanding of the lining behaviour, it is acceptable to consider the primary

Below: ***Work at Fisher Street took place under one of the most congested areas in London***

lining as part of permanent works. At Fisher Street this method was used with two variations: a sprayed secondary lining, for the east and westbound tunnel enlargements; and a cast in situ secondary lining for the headwalls of the tunnel enlargements, crossover and binocular tunnels.

SCL design contract C121 was awarded to Mott MacDonald in May 2009. The SCL design included the use of steel fibre reinforced (SFR) concrete, mainly for the primary lining, a regulating layer and a spray applied waterproofing system followed by sprayed or cast in situ secondary lining. In terms of durability, the project materials and workmanship specifications required a tunnel complying with an expected service design life of 120 years.

The contractor was required to carry out trials to demonstrate compatibility with the intended construction methods and suitability of concrete mixes. A few examples of these are: spray trials to investigate the reinforcement encapsulation, fire tests to examine the competency of the fireproof mix and site trials to demonstrate confidence on the contact grouting system.

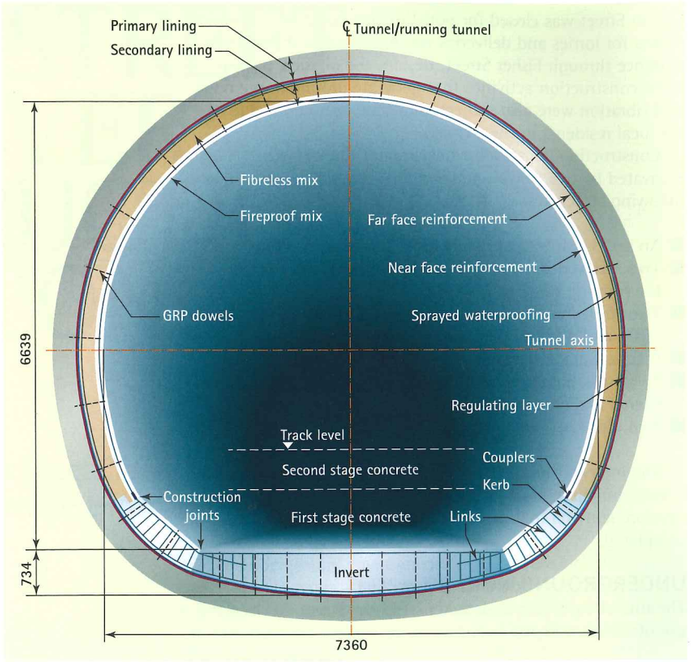
To achieve the required fire resistance (Eureka curve, 170 minutes), a "finishing layer" with a minimum 50mm thickness and polypropylene fibres at a dosage rate of 1kg/m³ was required. This layer served two main objectives; to ensure a steel fibre free finish of the SCL and provide a passive fire protection to the structure.

CONSTRUCTION SEQUENCE

Logistics were the major challenge during the construction of the Fisher Street caverns and crossover tunnels, working in parallel to First Stage Concrete works from Tottenham Court Road to Farringdon. The difficulty of the interface of these activities with the removal of backup gantries of two TBMs from Farringdon, via the small intervention adits from running tunnels to the Fisher Street shaft, was only matched by the complex geometry of the tunnels.

Achieving progress despite the on-site constraints and providing an uninterrupted supply of concrete into the tunnels was another big challenge. This was overcome by providing two vertical boreholes constructed from the KTT, between the Crossrail tunnels and KTT level, that allowed for direct discharge of concrete into the tunnels, which was then transported via concrete mixer trucks to the working faces. This allowed the removal of the delivery of thousands of cubic meters of ready mix concrete (batched off-site and delivered in 7m³ concrete trucks) from the small footprint of the Fisher Street site and allowed good progress with the long continuous concrete pours.

Figure 2 presents a cavern cross section with its main features and construction sequence for a section of approximately 60m² and 350mm secondary lining design



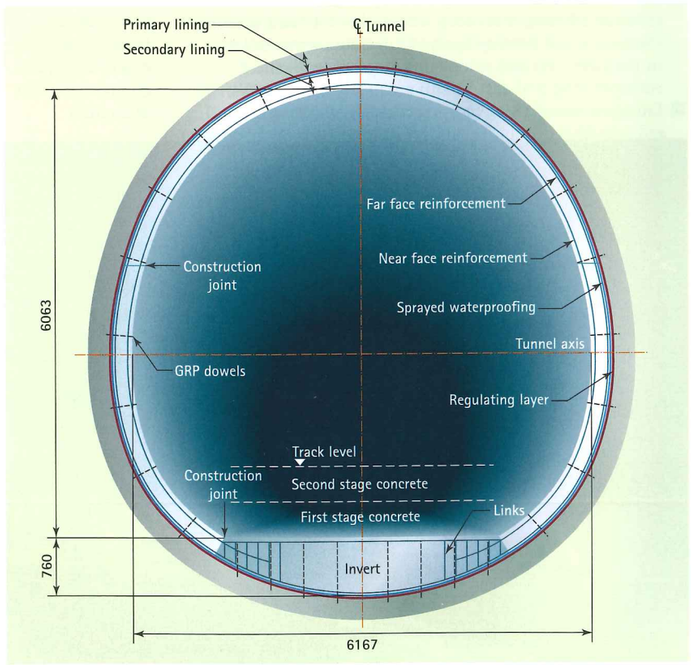


Table 1. Secondary lining construction sequence

Construction stages	Sprayed secondary lining	Cast in situ secondary lining
1	Spray Regulating Layer over PL	
2	Install GRP dowels	
3	Spray Waterproofing Membrane	
4	Cast Invert	
4A	Cast Kerbs	N/A
5	Install Far Face Reinforcement	
5A	Spray S1 Layer	N/A
6	Install Near Face Reinforcement	
6A	Spray S2 Layer	N/A
7	N/A	Cast Walls
8	N/A	Cast Crown
9	N/A	Contact Grouting

Source: Authors

thickness. Regarding Figure 3, this presents similar information for a typical crossover section of approximately 45m² and 250mm secondary lining design thickness. Table 1 presents the simplified construction sequence which will be discussed in the following numbered paragraphs.

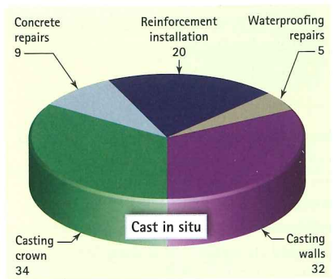
A. A fibreless mix was sprayed for the regulating layer over the primary lining (PL). This was done to prepare a surface free of any irregularities and ready to receive sprayed waterproofing membrane application. Surface roughness was checked through a comb test, in which no troughs greater than 10mm were desired, while ensuring no steel fibre protrusion from the PL.
B. Installation of Glass-Reinforced Polymer (GRP) dowels for supporting the secondary lining (SL) reinforcement. The installation of dowels, prior to spraying the waterproofing, saved time and material as it reduced the potential need to repair the waterproofing membrane around the dowels (if done in a later stage).
C. After the application of the waterproofing, the area was protected and allowed to cure sufficiently to achieve Shore A hardness of 50 for sprayed SL and 30 for cast in situ concrete, to avoid damage to the waterproofing. Although, a detailed study on waterproof material quantities has not taken place it was clearly noticed that if care was not exercised during the waterproofing application, an extra coat(s) could be required on top of what would normally be expected. An acceptable finished surface should be free of any defects (pin holes, etc.) and in an optimal range of between 4 and 10mm.
D. For the casting works, special attention was given to waterproofing overlap areas that would require remedial works if damaged. Construction joints were prepared painting the stop ends with a concrete retarder and jet-washed to achieve a "green cut". The use of crack inducers to work as contraction joints allowed time gains in erecting the formwork.
E. The greater bending moments in the kerbs area resulted in a higher density of reinforcement in these regions. One of the challenges here was to reduce the risk of rebound encapsulation at the radial joint. As a field change design option the joint was still kept radial but with a step, higher at the back, allowing the rebound to fall in front of the spraying.
F. Special care was taken so the reinforcement installation did not damage the waterproofing membrane. If damage occurred or leaks were introduced the area needed to be repaired by hand painting the waterproofing membrane and ensuring a 300mm overlap with the undamaged waterproofing membrane. The maximum size of the rebar was limited to 20mm to minimise the risk of poor encapsulation.
G. As shown in Figure 5 (page 50), the maximum stretch of spraying activity dictated the bay lengths and was dependant on the type of plant, exclusion zones, cross-section of the cavern and the type of joints to be achieved. The sprayed concrete operation followed smooth back and forth oscillating nozzle movements from the lower axis level towards the crown in a steady uninterrupted flow. The lining was built up by making several passes (maximum 100mm) of the nozzle over the working area. The thickness was controlled using the laser total station systems (through TMS Office from Amberg Technologies) and lacer bars to guide the sprayers. The use of stop ends showed good concrete compaction. The accelerator dosage: 5-6 per cent in the shoulders and 6-8 per cent in the crown. To suit the contractor's method of construction, an additional hydrophilic strip was required to be installed on the longitudinal (cast-shotcrete) and circumferential (shotcrete-shotcrete) construction joints of the adjacent bays in EBX and WBX to ensure water tightness at the joints.

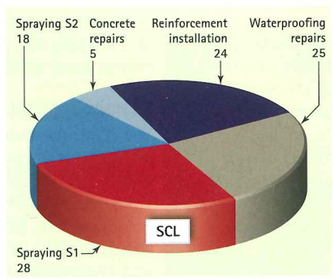
For near face reinforcement, the

Opposite, top: ***Figure 2, Tunnel enlargement cross section***

Opposite, bottom: ***Figure 3, Crossover cross section***

Below: ***Figure 4, Relative percentage of time per construction activity***





use of couplers for kicker bars, at the kerbs, allowed the easy installation of reinforcement after spraying S1. This reduced the risk of shadowing in the S2 layer by avoiding the need to spray the S1 layer through two layers of reinforcement.

H. The second layer - S2, has the requirements for a minimum 50mm lining of polypropylene fibres, and a design cover of 60mm. The requirement to spray a separate fireproofing layer was omitted with a value engineering proposal to incorporate a fireproof mix within the S2 layer. The 350mm of SL layer in WBX and EBX was then made up of first layer approximately 230mm of non-fibre reinforcement (has FF reinforcement) and a second layer S2, approximately 120mm with polypropylene fibres in the concrete mix. This option reduced the risk of delamination issues between S1 and S2, since both layers present an adequate thickness and encapsulate one of the reinforcement faces.

I. A self-compacting concrete (SCC) mix (C32/40) with GGBS and polypropylene fibres was developed for casting the walls and crown in the crossover, this mix had to be developed at short notice due to a nationwide shortage of pulverised fly ash (PFA) at the time of the works. The mix has two main advantages: it replaced the use of PFA with ground granulated blast furnace slag – reducing the project programme risk with any potential delays in PFA supply. Secondly, improvement in quality of the concrete finish - the use of SSC mix reduces the risk of segregation and poorly compacted concrete. It worked out to be a good solution for areas with heavy or complex arrangement of reinforcement.

J. The separation of pours into two stages, wall and crown, was required to allow more flexibility to the works, as the crossover was necessary for access to the first stage concrete team working in both running tunnels at the time of the works. This changed the original design plan to spray the crossover SL. The crown was cast using a Doka travelling formwork, assembled on site and pulled from EBX cavern westwards towards WBX with chain blocks using channel rails.

K. Any possible voids in the crown were contact grouted using a pumpable grout of 0.6 water/cement ratio with three per cent plasticiser, through pipes set in the concrete

*Above: **Figure 5, Spraying bay S1 in EBX***

for this purpose along the highest areas of the tunnel. It was important to test the mix and the grout tubes at their maximum length prior to use. This was achieved through a full scale test in a slab built only for this purpose. The tubes were adequately fixed, to the reinforcement, to the highest areas to avoid displacement during casting works.

The secondary lining works related to the crossover tunnel and the western tunnel enlargement at Fisher Street took place from the first week of March to the last week of October 2015, a total of 35 weeks of the programme. Based on the shift reports and the design volumes for the lining, a construction rate for both SCL and cast-in-situ linings has been estimated. The rates quoted are based upon a 24-hour, seven-day working pattern and 100 per cent utilisation. There were no distinct differences in general delays and breakdowns noted.

The relative percentage of time spent in each construction activity, per cycle, has been derived and presented in Figure 4 (page 49). The data shows that the casting of the walls took almost the same amount of time as the casting of the crown. On the other hand the study demonstrates that spraying S2 took 30 per cent less time than spraying S1, since S2 is thinner than S1.

It should be noted that this is not a detailed study, since it relies mainly on shift reports and design concrete volumes, and it did not consider a number of variables that affect the production process. Nevertheless, an average production rate for the cast-in-situ lining at junctions (crossover tunnel) of 2.8m³/day and of 8.5m³/day for the SCL (western tunnel enlargement) would be a fair comparison.

CONCLUSIONS

This paper presented the construction of a secondary lining at the Fisher Street site, highlighting the main challenges of the project and the solutions developed by the engineering team. The project requirements and constraints discussed here are site specific, however, lessons learnt and good practices adopted can be taken forward to similar tunnelling projects with reasonable engineering skill and care

The authors would like to thank to all parties involved in the works at Fisher Street Crossover, particularly to BFK, CH2M, Crossrail and Mott MacDonald.

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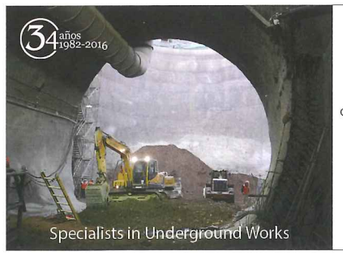

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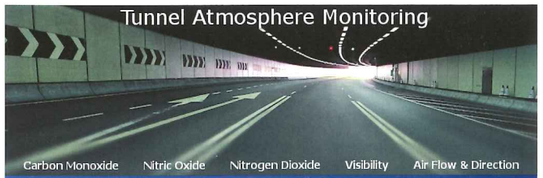

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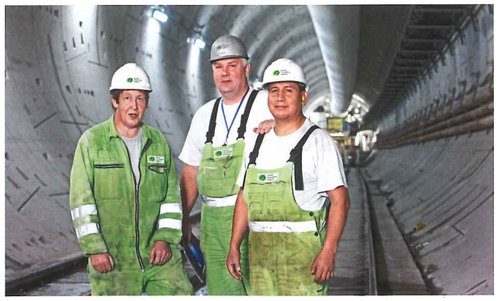

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What's on

2016

TBM Applications II Seminar
6-7 June 2016
Bergen, Norway
During the period from early nineteen seventies to early nineties more than 250 km of tunnels were excavated in Norway by the use of TBMs After this period the development of hydropower came more or less to a stop and the same was the case with the application of TBMs. Internationally the development has gone the opposite way. But now in Norway, things are changing.
www.tunnel.no/events/

Swiss Tunnel Congress 2016
15-17 June 2016
Lucerne, Switzerland
The annual Swiss Tunnel Congress (STS) is organised by the Swiss Tunnelling Society and is the premier event for tunnelling in Switzerland. Approximately 800 delegates attend from around 15 nations to take in the high quality presentations. This year there is a particular focus on fire and safety, as well as past and future Swiss projects.
www.swisstunnel.ch/en

Urban Underground: the Next Economy
23 June 2016
Rotterdam, the Netherlands
A full-day programme which addresses how careful deployment of the sub-surface can improve the value of life in our cities. The urban underground possesses a large untapped potential that could contribute significantly to the sustainable and resilient development of cities in the future.
www.iabr.nl

GeoChina International Conference
25-27 July 2016
Shandong, China
This conference will provide a showcase for recent developments and advancements in design, construction, and safety Inspections of transportation Infrastructures and offer a forum to discuss and debate future directions for the 21st century. Conference topics will cover a broad array of contemporary technical issues.
www.geochina2016.geoconf.org

Urban Underground Space & Tunnelling Summit
6-9 September 2016
Singapore
Asia's Leading Urban Underground Space & Tunneling Summit will return to discuss leading practices, innovative techniques and sustainable solutions for design, engineering and construction of tunnels and underground space.
www.equip-global.com

ISCOCARP Conference
12-16 September 2016
Durban, South Africa
The International Society of City and Regional Planners (ISOCARP) is a global association of experienced professional planners. It was founded in 1965 in a bid to bring together recognised and highly-qualified planners in an international network. The ISOCARP network brings together people from more than 80 countries worldwide.
www.isocarp.org

No Dig Live UK
20-22 September 2016
Peterborough, UK
Following the success of No Dig Live UK held in September 2014, the 13th biennial trenchless technology exhibition, outdoor demonstrations and seminars will return to Peterborough.
www.nodiglive.co.uk

Innotrans
20-23 September 2016
Berlin, Germany
InnoTrans is the leading international trade fair for transportation technology, and takes places every two years in Berlin, Germany. The event is sub-divided into the five segments Railway Technology, Railway Infrastructure, Public Transport, Interiors and Tunnels.
www.innotrans.com

Nordic Grouting Symposium
26-27 September 2016
Oslo, Norway
The Norwegian Group of Rock Mechanics (NBG) and the Norwegian Tunnelling Society (NFF) have the pleasure to announce that the 8th Nordic Grouting Symposium will take place 26-27th of September 2016. Nordic colleagues are invited to present papers and exchange experiences.
www.nordicgrouting.com

TAC Conference
12-15 December 2016
Ottawa, Canada
The Tunnelling Association of Canada is pleased to welcome you to TAC 2016 Ottawa. With the theme Capitalising on Underground Infrastructure, the 2016 TAC conference will include plenary presentations, technical sessions, and a trade exhibition all designed to highlight advancements in tunnelling.
www.tac2016.ca

Expo Tunnel
19-21 October 2016
Bologna, Italy
ExpoTunnel is an exhibition dedicated to the world of tunnelling, drilling, mining, underground construction and research. It is an opportunity to meet in a global framework of supply and demand of high technology and its field applications, with the chance to learn new methods and harness new techniques.
www.expotunnel.it

Bauma China
22-25 November 2016
Shanghai, China
Bauma China is Asia's largest and most important event for the construction industry. It attracts international buyers – a fact that guarantees a high return on your investment as well as sustainable success. The show is a platform for product presentations and a grand industry party for communication.
www.bauma-china.com

TBM Digs
16-18 November 2016
Istanbul, Turkey
Turkey has a great potential for tunnelling work, and in the near future the country is expecting to see upwards of USD 35bn of investment in the underground. The Turkish Tunnelling Society is also rapidly expanding its membership. This looks to be an impressive event following on from last year's which was hosted in Singapore.
www.tbmdigsturkey.org

Bauma Conexpo India
12-15 December 2016
Delhi, India
The International Trade Fair for Construction Machinery, Building Material Machines, Mining Machines and Construction Vehicles—provides the construction industry in India with a professional platform for networking, investment and the exchange of ideas and information. The 2014 event welcomed some 26,018 visitors.
www.bcindia.com

2017

World Tunnel Congress
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 and its engineers are keen to share their combined expertise with attendees.
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

Aftes International Congress
13-15 November 2017
Paris, France
The congress of the French tunnelling association returns to Paris in 2017. Hosted at the Palais des Congrès, its theme will be 'The Value is Underground'.
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 experts visited Stuva Expo 2015. Preparations are already on the way for Stuva Expo 2017, which will take place in Stuttgart.
www.stuva-expo.com/en/

2018

World Tunnel Congress
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. The region boasts a number of impressive megaprojects built through challenging ground conditions.
www.uaesocietyofengineers.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.

Developments in the jacked-concept for urban shallow tunnels
16 June 2016
The use of jacked installation for tunnels and structures has been greatly extended in capability and application in the last 50 years. This presentation reviews the past developments and focuses on the recent innovations and applications to large non-circular underground structures including underpasses below rail and road, subways, shallow tunnels and green tunnels. This will be put in the context of future projects, such as High Speed Two for putting rail underground, Hammersmith Flyunder and many others. Innovative concepts for creating large underground structures and caverns in soft soil – which could find extensive use will also be presented.
Speakers: Andrew Robinson, Christopher Howe, and James Thomson, all of Jacked Structures

The Emscher Interceptor
22 September 2016
Klaus Rieker of Wayss & Freytag will give a presentation on the construction of the Emscher wastewater tunnel over no less than 35 km from Dortmund to Bottrop. The contract was awarded to Wayss & Freytag Ingenieurbau in January 2012 and includes 47km of pipe jacking and the construction of over 100 shafts. The River Emscher in the German Ruhr District has been used for disposing of wastewater. In the early 1990s, it was decided to replace the existing open wastewater system with a sewer system and to restore the River Emscher to its natural state. The project is divided up into a number of individual contracts. Pipe jacking ranged from 1.6 to 2.8m internal diameter with interlinking conduit sections in excess of 1,100m in length.
Speaker: Klaus Rieker, Wayss & Freytag

BTS Conference and Exhibition
11-12 October 2016
The British Tunnelling Society is pleased to announce the highlight of its 2016 events calendar. Due to be held at the QE2 Conference Centre in Westminster, the BTS Conference and Exhibition is not only the UK's largest tunneling and excavation event, it is the only event in 2016 supported by the British Tunnelling Society, making it an essential destination for senior, decision-making tunnelling professionals involved in the design, management and maintenance of today's tunneling and underground infrastructure. Presentation synopses of 250 words are now being accepted for consideration with a deadline of 26 February. For more details please visit the society website.
Please note that this event is not located in the ICE

Harding Memorial Lecture
20 October 2016
The Harding Lecture is named after the founder Chairman of the British Tunnelling Society, Sir Harold Harding and is given every second year. The lecture is delivered by an eminent speaker who presents a lecture on a tunnelling related subject they have some specialism in, or otherwise a passion for.
The speaker has yet to be confirmed

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

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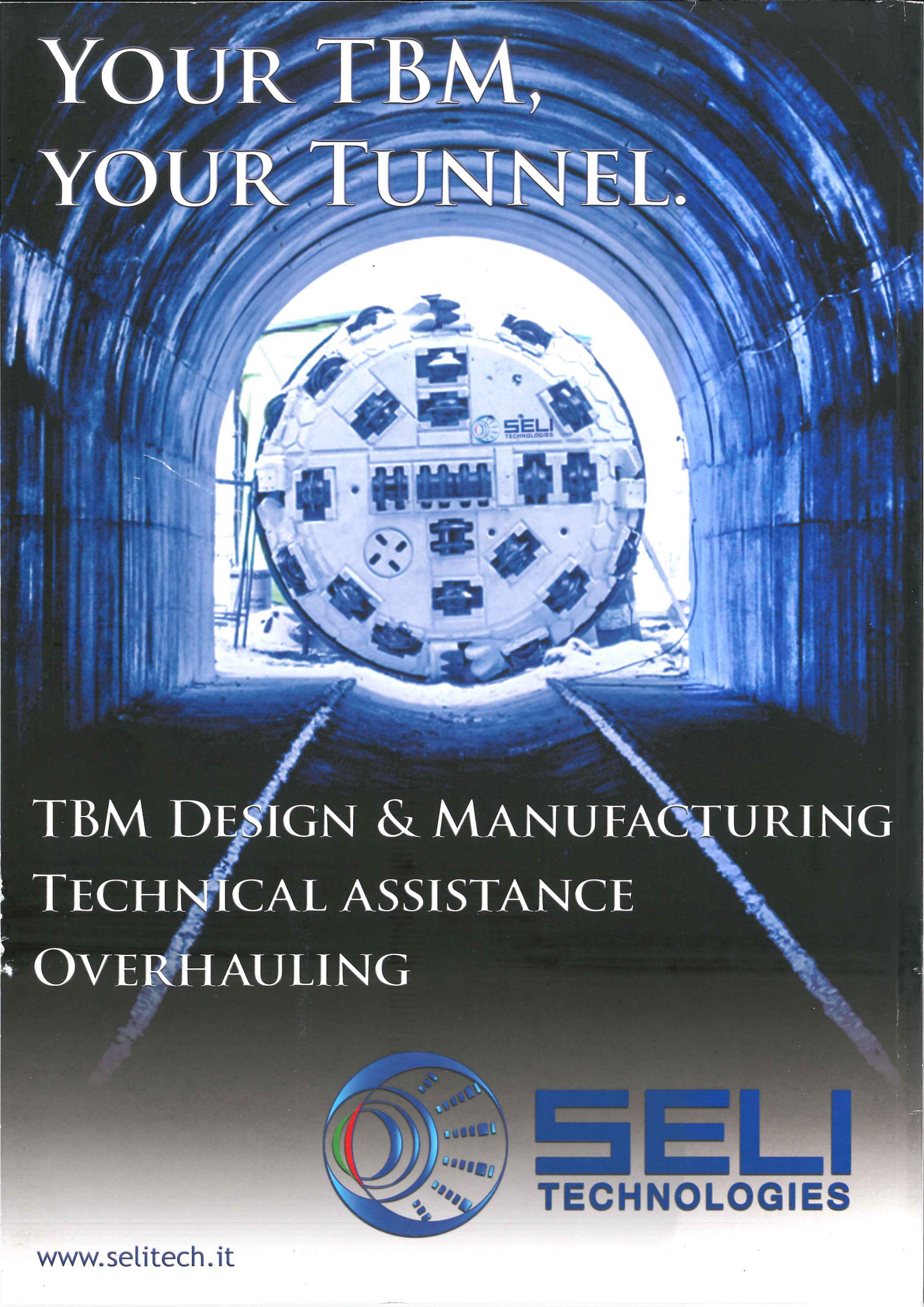

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