INTERNATIONAL EDITION
October 2016

Tunnels AND TUNNELLING

FOLLO FOUR

TBMs return to Norway for this rail link

Fibres • USA • Precast

DUST TO DUST

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

NO MATTER, the type of infrastructure, going underground is preferable in most cases, but really the choice is made due to limited or costly surface space. The choice to go underground is a necessity to meet the demands of a growing population. But in some parts of the world there is another problem created: the question of what to do with the dead. For where burial is the preferred solution, surface space (and underground real estate down to 6ft) begins to appear very finite. The solution, as always, is the use of deep underground space.

Israel-based contractor Rolzur Tunnelling is leading the way in underground interment as 'project entrepreneur' (responsible for complete design and construction) for a new underground burial complex in the country. Design has had to take the Mishnah into consideration. This is a summary of the Oral Torah that was compiled by rabbis in the 3rd century AD. It advises on all Jewish aspects of life and includes a section on how one should execute burial tunnels, for example the appropriate distance between graves and required rock quality to avoid collapse. According to Rolzur Tunnelling general manager Arik Glazer, this is considered one of the earliest guidelines for tunnelling.

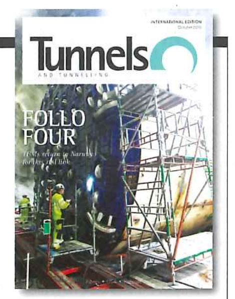
This is something of a forgotten tradition. In ancient times, burial in tunnels or caves was common in the region. Readers might recognise a famous example involving the entombment of a Galilean carpenter.

Returning to the present, initially Rolzur Tunnelling had to carry out a pilot project involving two 50m-long roadheader excavated tunnels that were 10m wide and 6m high. Then began the ongoing main project that comprises more than 1,500m of tunnels at 14m wide and 16m high excavated in Dolomitic Limestone up to 120MPa. It also calls for a 55m-deep shaft with a cross section of 24x28m. The plan of the cemetery involves precast stack burial in levels alongside ground burial, as is the common burial practice. In addition Rolzur is preparing thousands of burial spots (niches) excavated directly in the rock by bespoke drilling machines designed for that purpose.

The shaft will be used for burial as well and it will incorporate elevators and all infrastructure such as ventilation of the complete site. The solution for which will incorporate the final result of a major CFD study that is currently be finalised with regards to fire and smoke control, as well as an evacuation plan. All parameters including lighting, ventilation and humidity will be controlled from a centralised computer system.

The project is currently being excavated. The shaft is almost complete and the site is in the vault and bench stages. Stage one (5,000 out of 22,000 burial plots) will be delivered to the client by the end of 2017

Cover
This issue's front cover shows TBM preparation for the Follo Line in Norway. A rare use of TBM technology there.



Next issue
In the next issue of Tunnels and Tunnelling we have a report on difficult site conditions with a horizontal directional drilling job in the Middle East, a report on Iceland's Vadlaheidi project, a Q&A with the ITA's Tarcisio Celestino and a BTS report on Sochi.

This month...

20 YEARS AGO

Previously undetected caverns below an old monastery are delaying start-up of the next EPBM drive from the Baixa-Chiado East Station towards the Duque de Cadaval shaft on the Lisbon Metro Extension project. Stabilisation work in the caverns area is now in progress and the EPBM will not be restarted until work is complete.
Tunnels and Tunnelling, October 1996, p.7

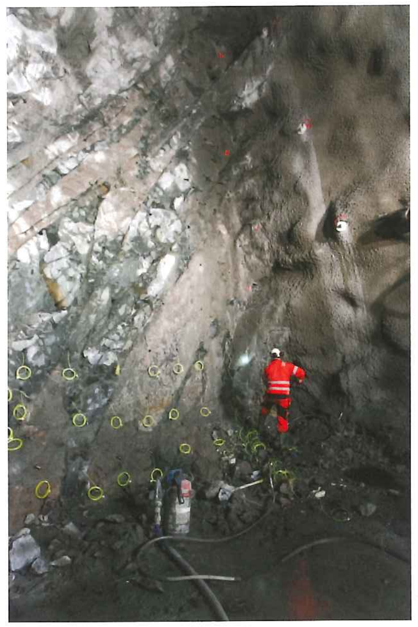
30 YEARS AGO

Giant precast concrete segments, forming what are believed to be the world's largest concrete shaft rings, and the first use of waterproof gaskets in the UK, were two features of the first stage of the GBP 41M Liverpool Sewage Treatment just completed by Mowlem. North West Water Authority awarded a design and construct contract for the two shafts to encourage contractors to offer suitable alternatives.

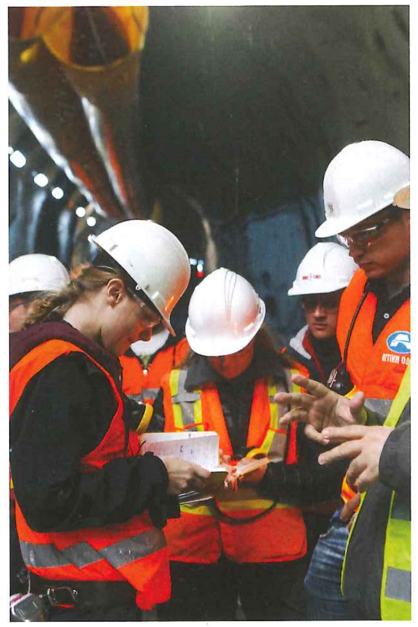
Mowlem and Buchan put forward a scheme using giant precast rings for the 35.5m-diameter, 20m-deep pumping shaft. Each ring consists of 30 segments, each 700mm-thick, 1,500mm-deep and 3,200mm-long.

The shafts were sunk through fill and clay into the underlying Bunter Sandstone. The water table was only 2.6m below ground so seven dewatering wells were required.
Tunnels and Tunnelling, October 1986, p.9

22 - The SR99 project in Seattle, Washington



25 - The Follo Line in Norway



36 - A field tunnelling course

46 - Excavation at Farringdon Station, part of the Crossrai project

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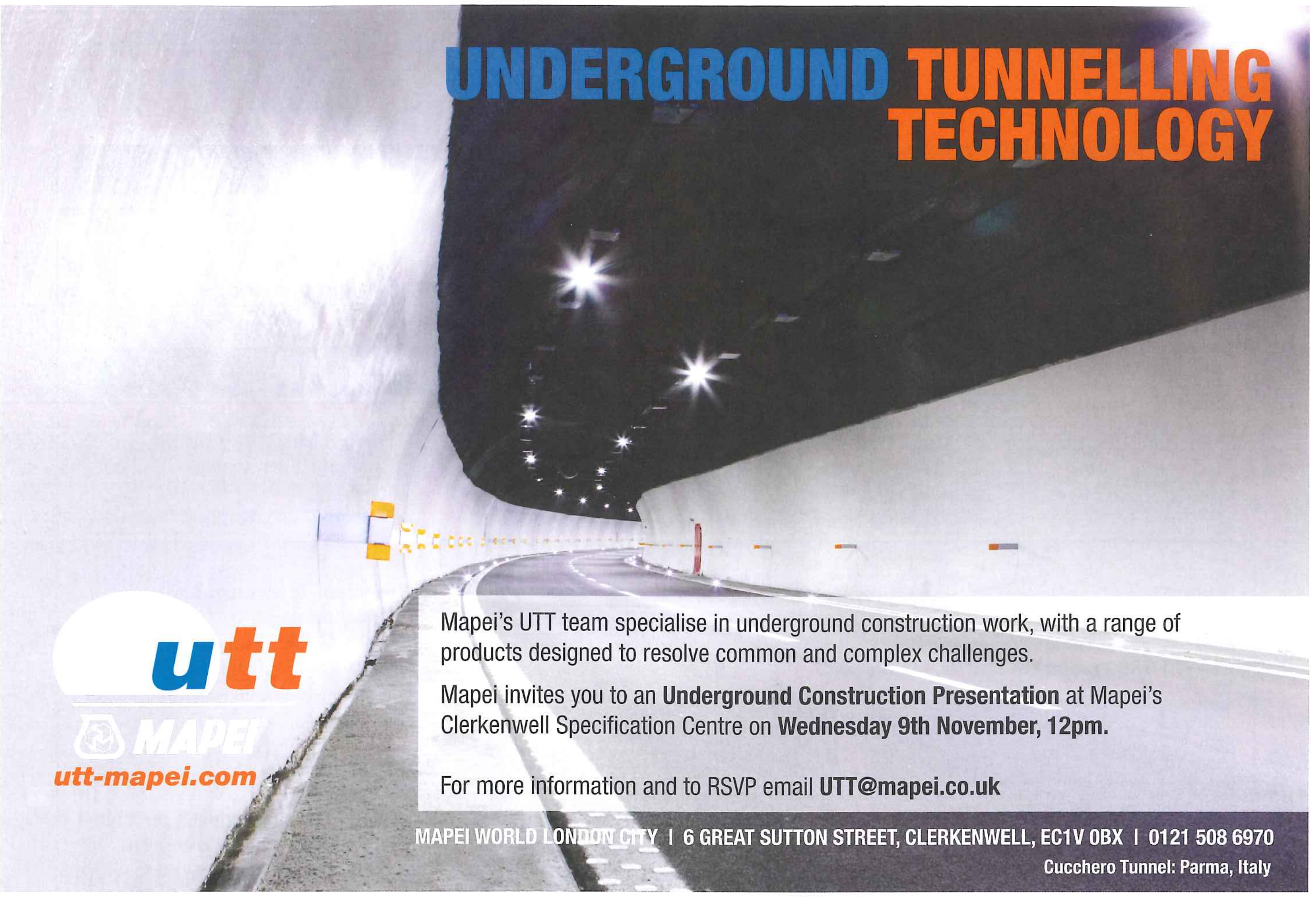


WASHINGTON STATE SUPREME COURT WON'T HEAR BRIGHTWATER LAWSUIT

USA — The Washington State Supreme Court has declined to review a lower court ruling that affirmed King County is entitled to more than USD 129M in damages from a tunnelling contractor that defaulted on key contractual obligations as part of the Brightwater tunnel construction, the county announced September 12.

This order confirms the previous judgment in King County Superior Court, which was upheld by the Washington State Court of Appeals.

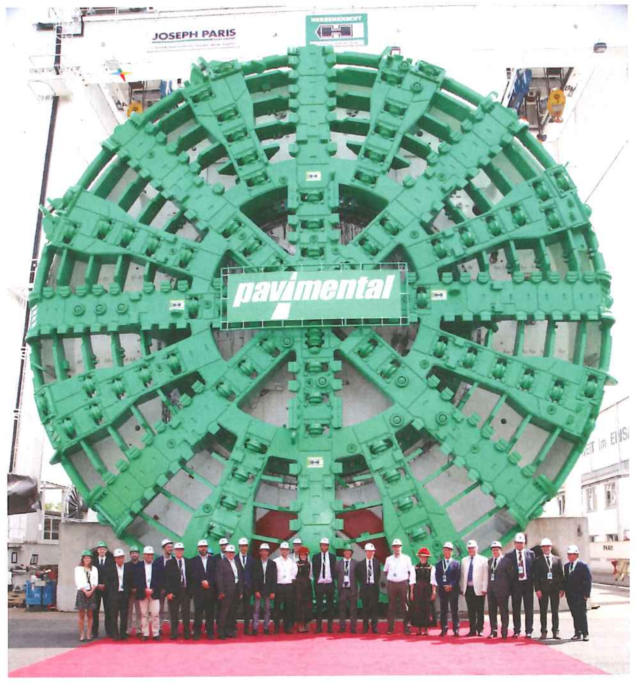
"The ruling by the state Supreme Court is a victory for King County ratepayers," said King County executive Dow Constantine. "We will use the funds we recovered on behalf of our customers to protect water quality throughout the region."

In December 2012, a jury awarded King County USD 155.8M in damages after finding Brightwater tunnelling contractor Vinci Construction Grands Projets/Parsons RCI/Frontier-Kemper (VPFK) defaulted on key contractual obligations. The judgment was adjusted to USD 129.6M to reflect the jury's award of USD 26.2M to the contractor. The Supreme Court has accepted review of a separate petition filed by the performance bond surety providers that appeals the award of more than USD 15M for legal fees to King County.

VPFK was awarded the USD 212M construction contract to build the two central Brightwater conveyance tunnels in 2006. It was the second of four Brightwater construction contracts to build a 13-mile (21km) tunnel to carry treated wastewater from the treatment plant north of Woodinville to a deep-water marine outfall in Puget Sound.

King County said, two TBMs required extensive repairs that threatened to delay the completion of Brightwater's conveyance tunnel by up to three years. Though VPFK repaired one machine and completed a 2.2-mile (3.54km) tunnel drive between Kenmore and Bothell in 2011, the County could not accept the lengthy delay and additional cost the contractor proposed for the repair of the second machine to complete tunnelling.

Joint venture contractor Jay Dee/Coluccio completed mining on the final 1.9-mile (3km) section of Brightwater tunnel in August 2011. The tunnel has been in operation for nearly four years.



The Santa Lucia TBM in Schwanau, Germany

Largest European TBM stands ready

GERMANY/ITALY — Herrenknecht has completed the EPBM for the Santa Lucia road tunnel in Italy. The 15.87m titan is 200mm more in diameter than the previous record holder, the 15.62m-diameter Sparvo machine.

TBM acceptance was held on 29 August with construction company Pavimental representatives of client Autostrade per l'italia as well engineers and the Board of Herrenknecht in attendance.

The Santa Lucia tunnel will run for 7.5km through heterogeneous subsoil in the Appenines near Florence and will take three years to build.

Ottawa initiates traffic tunnel environmental assessment

CANADA — The Ottawa City Council voted 21-2 on September 13 to move forward with the environmental assessment for a new tunnel in its downtown connecting the Macdonald-Cartier Bridge and Highway 417 for mixed traffic.

In August the City released a feasibility study finding the 3.4km-long tunnel is technically possible, and would reduce truck traffic on downtown streets. It undertook the study with a CAD 750,000 (USD 583,000) funding contribution from the Government of Ontario.

The study found the preliminary cost estimate for construction to be between CAD 1.7bn and CAD 2bn (USD 1.32bn to 1.5bn). The city council intends to approach the province to also help fund the environmental assessment.

The council also approved a motion directing city staff to explore the feasibility of banning all trucks from the downtown, with the exception of those making a delivery if the tunnel is constructed.

If a tunnel were to be built, it would be available for mixed-traffic use and would divert between 20,000 and 25,000 cars and trucks per day.

Previously Ottawa has said the forecasted traffic demand that would use this route is too small to justify an investment in a truck-only tunnel. Thirty-five per cent of truck traffic currently using downtown streets would not use the tunnel because they need to make local on-street deliveries or pick-ups.

Furthermore, any trucks transporting dangerous goods would be prohibited from the tunnel due to safety concerns.

Michels adds microtunnelling manager

USA — The trenchless construction veteran Brenden Tippets has joined Michels Corporation as microtunnelling manager, the company announced on 22 August. Tippets has more than 20 years of experience in wide-ranging aspects of heavy civil construction, including significant experience in microtunnelling, tunnelling and pipejacking. His specific areas of expertise include design-build trenchless projects, extensive contaminated ground water remediation, and construction in deep and difficult soil conditions in dense urban settings.

As microtunnelling manager, Tippets will guide the growth of microtunnelling among Michels' trenchless construction services.

Brian Gash joins Mott MacDonald

GREAT BRITAIN — Mott MacDonald has appointed Brian Gash as its highways programme director for the UK. He will be responsible for coordinating engagement with client Highways England.

A Mott MacDonald spokesman said: "A registered project professional with the Association for Project Management, Brian has worked in the construction industry for over 30 years. He joins Mott MacDonald from Highways England where he was group leader and the senior responsible owner (SRO) for Major Projects South West.

"During this time he was responsible for the delivery and governance of six major infrastructure schemes under new Highways England guidelines as part of its Road Investment Strategy programme. Prior to this Brian was SRO at the Highways Agency for the delivery of four SMART motorway schemes on the accelerated delivery programme.

"As well as bringing operational experience in major projects and programmes, Brian has also undertaken a number of consultancy roles. He was infrastructure engineer on the Millennium Dome site, has worked with Highways England communications and strategy planning and supported the Department for Transport and the Parliamentary Under-Secretary on schemes in south west England."

Commenting on his new appointment, Brian said: "One of the greatest challenges facing Highways England is delivering the substantial increase in investment on England's motorways and major A roads. I'm keen to develop ways in which we can work with them to realise their ambitions."

Brian Gash

Tunnelling ends on Eglinton

CANADA— he Ontario Ministry of Transportation announced August 17 tunnelling is now complete on the 10km of underground alignment for the Eglinton Crosstown LRT line.

Two TBMs boring the eastern segment tunnels arrived at Yonge Street finishing after mining 3,300m from where they started just east of Brentcliffe Road in September 2015. Two more TBMs completed tunnelling on the western segment of the Crosstown when they reached Yonge Street in May 2016.

The new LRT line will have 25 stations and stops along Eglinton Avenue between Weston Road and Kennedy Station, and will also link to 54 bus routes, three TTC interchange subway stations, and GO Transit.

Construction shoring is now underway on three Crosstown stations, including Keelesdale, Laird and Avenue.

By 2031, the Eglinton Crosstown LRT is expected to carry approximately 5,500 passengers per hour during peak travel times, with daily boardings estimated to be 162,000 and an annual ridership of about 50 million.

Atlanta to add 600ft to its airport tunnel

US — Hartsfield-Jackson Atlanta International Airport (ATL) officials announced September 7 they will host an informational meeting later this month to discuss a tunnel extension project at the airport.

As part of a bigger USD 6bn capital improvement program at the airport, the work will extend the plane train tunnel to the west from its existing endpoint under the domestic terminal. The extension will create a more efficient train turn-back operation, allowing for a significant reduction in train headway (the time interval between trains), which will yield an increase in passenger capacity.

The scope of the project includes the design and construction of a 600ft-long (183m) tunnel. Also included are vertical circulation components inside the terminal, evacuation stairways, running tracks and crossover equipment.

Due to the project's unique requirements, ATL officials will host an industry-geared meeting Tuesday, September 20. Construction firms familiar with transportation-based tunnel projects are invited to attend.

A link to the informational meeting can be found here: https://atlnextplanetrain.eventbrite.com

Ottawa releases study on tunnel feasibility

CANADA — A tunnel between the Macdonald-Cartier Bridge and Highway 417 for mixed traffic is technically possible, according to a recently completed feasibility study, the City of Ottawa said on August 17. It undertook the study with a CAD 750,000 (USD 583,000) funding contribution from the Government of Ontario to explore the tunnel option as a means of reducing truck traffic on downtown streets.

The 3.4km tunnel would extend with two lanes in each direction from the Macdonald-Cartier Bridge to Highway 417 at Vanier Parkway and Riverside Drive via a cross-town route under Lowertown and Sandy Hill.

The study found the cost estimate for construction to be between CAD 1.7bn and CAD 2bn (USD 1.32bn to 1.5bn). Ottawa said the forecasted traffic demand that would use this route is too small to justify an investment in a truck-only tunnel.

FEHMARN PUBLIC CONSULTATION COMPLETE

GERMANY — The public consultation period for the Fehmarnbelt tunnel ended on 26 August. The documentation was an updated application for planning permission. Members of the public, companies and organisations had the opportunity to study materials for just over a month. An earlier consultation was put to the public in 2014-15.

The independent regulatory authority in Kiel is responsible for the consultation and is currently documenting all the responses before sending them on to the project teams.

The Fehmarnbelt fixed link's German section must be approved by the German authorities before construction can get underway. In Denmark, the Fehmarnbelt fixed link's Danish section was approved by the adoption of the 2015 Construction Act.

"We're looking forward to receiving all the responses from the regulatory authority in September," says Claus Dynesen, Femern A/S Project Director. "We will then begin the process of analysing them and, together with the authorities in Schleswig-Holstein, assess the next steps. We at Femern A/S and our co-applicants on the German side, LBV Lübeck, will respond to all questions. We're ready with our team of internal and external German experts to provide comprehensive answers to all the questions raised."

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.

QUITO TBMS READY FOR DELIVERY

ECUADOR — Herrenknecht announced on 5 September that it had finished the construction of two TBMs in Schwanau, Germany, which will soon be delivered for Metro de Quito in Ecuador.

The mayor of Quito, Mauricio Rodas, visited for the technical acceptance with representatives of contracting joint venture Acciona/Odebrecht and client Quito Metro. The two EPBMs have 9.36m diameters and will tunnel at depths of 20-25m below the city.

Quito's new metro Line 1 will run more than 20km through the capital city, at an altitude of more than 2,800m above sea level. The tunnel lengths are 8,180m and 9,053m.

The TBMs are expected to start mining from the spring of 2017 through volcanic ground conditions of silt clay and tuff.

The new rail system is an important step in the modernization of the metropolis and in the future will transport more than 350,000 passengers daily.

The Quito TBMs ready for delivery in Herrenknecht's factory

Tunnel between Quebec City to Levis is feasible

CANADA — The results of a feasibility study presented on September 13 find a tunnel between Quebec City and Levis of 7.8km in length could be built for approximately CAD 4bn (USD 3.03bn). Quebec's Ministry of Transportation commissioned the study, which also investigated the geology and geotechnical factors, and noted sandy soil near the alignment. Construction would require ground improvement in these areas.

Bruno Massicotte, an engineering professor at Polytechnique Montréal made the presentation, and told local media the sand is water-bearing, which in the case of a major earthquake would liquefy, requiring a bigger, more robust tunnel.

Tunnelling completed on Northgate Link LRT

US — The TBM finishing the last drive on Seattle's Northgate Link LRT project has reached University of Washington station on September 2.

Sound Transit's tunnelling contractor, the Jay Dee/ Coluccio/Michels (JCM) joint venture, finished its remaining Northgate Link tunnel drive, of six, with TBM #1, the transit authority announced April 29. JCM had previously used refurbished TBM #1, manufactured by Hitachi Zosen, to mine the 230 tunnel contract for Seattle's University Link light rail project.

Trans-Pennine tunnel route options unveiled

GREAT BRITAIN — Five potential routes for the proposed Sheffield to Manchester tunnel have been unveiled. The Department for Transport calls it the most ambitious road scheme undertaken in the UK for five decades. A feasibility study released last year by Highways England said the project would include a tunnelled section that could range anywhere between 20 and 30km. This would make it one of the longest road tunnels ever built and would raise a number of challenges (see Editor's Comment, Tunnels and Tunnelling International December 2015, p.3). The study is part of the government's next phase of road improvements, which will get underway from 2020. The current Road Investment Strategy period covers 2015 to 2020. In the final stage of the study, due to be completed by the end of 2016, the strategic and economic cases for each option will be assessed and cost estimates will be provided. Some speculation can be read in the comment previously referenced.

Israel to build anti-tunnel wall

ISRAEL — The Israeli Defence Forces (IDF) have begun work to building a wall to block tunnels being constructed by Hamas into Israel.

It is the latest efforts to stop militants and smugglers crossing the heavily policed Israeli border. Local and international media has reported that the depth of the structure's foundations will stretch to "dozens of metres below ground". Recent tunnels into Israel have been 30-40m deep. The concrete barrier will stretch for 37 miles (59km) and will reportedly cost around USD 600M. It will be equipped with sensors to detect tunnelling activities.

LA TBM reaches second station

USA — The TBM mining the rail tunnels for the Crenshaw/ LAX line in Los Angeles broke through the station box for Martin Luther King, Jr. Station, the Los Angeles Country Metropolitan Transportation Authority (Metro) announced August 22. Walsh/Shea Corridor Constructors are using a 21.5ft (6.5m) diameter Herrenknecht machine, working south under Crenshaw Boulevard on the first of 1-mile (1.6km) twin tunnels. Three stations are underground, Expo/Crenshaw, where the TBM launched, Martin Luther King Jr. and Leimert Park. When the TBM reaches Leimert Park, Walsh/ Shea Corridor Constructors will turn around to mine the northbound tunnel.

In total the USD 2.058bn project will construction an 8.5-mile (13.7km) long line. Walsh/Shea Corridor Constructors is comprised of Walsh, Shea, HNTB, Comstock and Arup.

Terratec delivers microtunnelling system

THAILAND — Terratec recently completed the factory acceptance test of a new microtunnelling System in its assembly plant in Guangzhou, China. The test was attended by representatives of the buyer, Drill-Tech Thailand. The equipment will be used in the execution of a cable tunnel project in Bangkok for Metropolitan Electricity Authority (MEA).

The MTBM System can push standard DN1800 concrete pipes and it can be expanded to work with DN2000 pipes, being the length of each pipe 3,000mm. The machines are to bore in the typical Bangkok soil composed of clay, stiff clay and very stiff clay.

Blue Plains wins award

USA — The Blue Plains Tunnel team was recently awarded the Excellence in Dispute Avoidance & Resolution Award for projects with a budget of USD 250M or greater, Traylor Bros. announced. The award recognises completed projects that best exemplify the Dispute Resolution Board Foundation (DRBF) best practices. The team will be recognised at the DRBF 20th Anniversary Annual Meeting and Conference for the Al Mathews Award Dinner on September 23 in DC.

The Blue Plains tunnel is a 4.5-mile-long wastewater tunnel in Washington, DC, mined by TBM. Tunnelling finished last summer. The contractor is a JV of Traylor, Skanska, and Jay Dee. McMillen Jacobs Associates holds a prime contract with DC Water as part of the Program Management team.

The JV launched the TBM in July 2013, from a starting point at the Blue Plains Advanced Wastewater Treatment Plant, tunnelling along the Potomac River and crossing under the Anacostia River. The Herrenknecht machine built the southernmost segment of the Anacostia River Tunnel. The next section will be mined by another TBM launching at a site near RFK Stadium. The Northeast Boundary Tunnel is the longest portion of tunnel, which will follow. At the north of the tunnel system is the shorter First Street Tunnel.

SECOND SECTION INSTALLED ON TK TUNNEL

POLAND — Crews successfully installed the second section for the TK tunnel in Warsaw on September 12, Mammoet announced, using a rapid bridge replacement technique.

The transport company said during a rapid bridge replacement, the replacement bridge is constructed on a site near the existing bridge and the existing bridge is removed only after construction of its replacement has been completed. Once the replacement is ready, the old bridge is taken out and the new bridge is installed, keeping the amount of time that the bridge cannot be used to a minimum.

For this project, the tunnel section was constructed on a site near the railway. Once the 3,200 ton tunnel section was ready for installation, part of the railway was removed and the tunnel section was transported to its final destination using 104 axle lines of Self Propelled Modular Transporters (SPMTs). The rapid placement technique was carried out by Mammoet, Strabag and a group of local subsidiaries.

The application of this approach – a first in Poland – allowed the tunnel section to be installed with only 18 days of disruption to train services, with the transportation of the tunnel section in only two hours. The installation of the second tunnel section marks the end of this project for Mammoet. Mammoet also installed the first tunnel section in June of this year.

The prefabricated section is moved into place by 104 axle lines of Self Propelled Modular Transporters

Left: *Analysis of skeletons excavated as part of the Crossrail programme has identified the DNA of the bacteria responsible for the 1665 Great Plague of London.*

The Great Plague of 1665 was the last major bubonic plague epidemic in Britain and killed an estimated 100,000 people in London, almost a quarter of the population. Despite its scale, the pathogen responsible has eluded detection.

Modern scientific techniques have allowed scientists to isolate this DNA from teeth extracted from the skeletons. The enamel on the teeth acted as protective capsules, preserving the DNA of bacteria that was in the person's bloodstream at the time of death.

Molecular pathologists are now attempting to sequence the pathogen's full DNA genome. In doing so they hope to be able to compare the 1665 Great Plague to the 1348 Black Death epidemic as well as recent modern outbreaks

UNDERGROUND KNUCKLE BOOMS

One crane manufacturer has developed a crane it thinks would be ideal for underground applications and invites tunnellers to confirm

WORK IN CONFINED SPACES is a tricky discipline in modern tunnelling. While technological advances have given the contemporary engineer cleaner and more advanced equipment, a deal of the nous and lateral thinking experience that comes from regularly solving confined working challenges has disappeared from the industry.

Recently, some advances in knuckle boom cranes have been made that the tunnelling industry may be interested in. And one manufacturer, Hüfferman, is interested to know if its product, which it calls its 'e-crane' would be useful in underground settings.

KNUCKLE BOOMS

Knuckle booms are a type of crane with a boom that can articulate in the middle. The resulting available motion makes the apparatus look like a finger, so the articulation joint is referred to as a 'knuckle'. This allows these types of crane to get around objects and work in awkward environments.

Knuckle boom cranes can traditionally be ordered in various configurations, manufacturers fitting a boom to an existing chassis and so on. Customisation has been quite high.

The Hüfferman offering is an electric crane that is compact, and while the company has some optional extras it thinks would be useful for tunnelling (camera systems and radio remote control for unmanned operation, an individual emergency stop function and an explosion-proof electrical system for hazardous areas) the basic model is set. The crane is 1.99m wide, 5.6m long and 2.95m high. From this, the maximum extension of the boom is 29.1m with 15 degrees of articulation. The maximum lift capacity is 10,400kg at a 4m extension or 2,500kg at 2m. At the absolute maximum extension, lift capacity is 800kg.

DEVELOPMENT

The model was designed to work in industrial environments, such as automotive plants, food processing facilities and refineries. But the company has had its sights set on the tunnelling market as well, albeit without any success so far.

On the history of the product, Hüfferman's Daniel Janssen says: "The process began in 2011. We were noticing a lot of difficult assembly jobs [which require time-consuming dis- and re-assembly] and limited time was available to our customers. Additionally, enhanced environmental and energy guidelines, as well as a stronger commitment to worker health and safety were becoming evident. Our customers did not want to use internal combustion engines any more. So our assembly manager, Herbert Maack, suggested that we build an electrical crane ourselves to gain a competitive advantage and fulfil all our targets and requirements. We built up a project team of engineers and practitioners to work on a prototype. In 2012 testing and development began and in 2014 we built the first unit for sale."

They decided to ditch additional power packs, size being the more important factor, and improved steering from the prototype, achieving 270 degree steering. They also added a "pick up and carry" option that works up to 8t

Tunnellers invited to demonstrations

Hüfferman said it would like to invite tunnellers to test its crane and provide feedback at its site in Wildeshausen, close to Bremen in Germany. Any interested parties should contact Daniel Janssen: Daniel.Janssen@hueffermann.de

HERITAGE BRAND

A buoyed tunnelling industry and a number of domestic political gestures are restoring confidence in UK manufacturing. *Davy Markham* is one brand looking to increase its showing in the tunnelling industry. **Alex Conacher reports**

Above: ***Bearing housing manufactured for NFM***

ASK YOUNG ENGINEERS in the UK about domestic TBM manufacture and you might draw some blank stares. Homegrown capabilities are almost unheard of, certainly under-represented by the media, and are part of a wider malaise afflicting the UK manufacturing sector. The UK "does not build things" is the common refrain. It is some decades since the great prestige tunnelling project, at least on native soil, for the major UK-based heavy manufacturer Markham. In 1984/85 it manufactured three slurry shields under licence to Okumura of Japan. In 1987 it was awarded the contract for two 8.36m-diameter Channel Tunnel TBMs in joint venture with Robbins. In the mid 90's, under licence to Kawasaki Heavy Industries, they supplied a UK built slurry TBM to Nishimatsu for the Docklands Light Railway extension from Canary Wharf under the Thames to Greenwich, followed by numerous smaller projects for LU.

EXIT FROM TUNNELLING

So where did Markham go? Well, nowhere far away. The company has quietly been producing major TBM components ever since for JV partners TBM suppliers on many various international projects, along with large design and build products in other engineering markets. But in terms of full TBMs, after the decision was made to close the Markham facility in Chesterfield and move in with Davy in Sheffield in the late 1990s. The merger, orchestrated by then-owners Kvaerner, was more complex and expensive than expected, with a lot of plant needing to be moved. This was due to different machine tools and fabricating skills used by the two entities. DavyMarkham then looked at the projected opportunities for tunnelling and it was meagre compared to other products in their design and build portfolio. So as a TBM supplier, DavyMarkham pulled out of the business.

John Lindley, who left the industry when Markham left the tunnelling market and now newly re-appointed as sector lead of DavyMarkham's tunnelling business adds, "A great deal of time and effort went into bidding UK projects around that time such as the Jubilee line, and when all the TBM'S went overseas it was seen that there was a degree of short termism by both the UK government and industry, this was a major factor in our decision to pull out of the market." However the number of upcoming infrastructure projects in the UK coupled with a changing environment increasing the focus on the sustainability of U.K industry has fuelled a new enthusiasm within DavyMarkham. They certainly have the facilities, one of the largest machine shops in Europe coupled with fabrication and an assembly facility covered by a 350t lift capacity and all under one roof in Sheffield. In 2010 DavyMarkham was bought by an Indian concern, IVRCL. According to Bill Clark, (the new chief executive under new owners Hughes Armstrong) the previous owners were more focused on the Indian market. Some difficulties there led to it neglecting the UK business and DavyMarkham started to decline in other sectors. Then, in October 2014, the ailing company was "returned home" by UK-based industrial group Hughes Armstrong Industries, as it acquired Davy Markham from IVRCL. And now, with homegrown management and a domestic tunnelling industry in the ascendancy, Davy Markham is setting its sights on the underground.

For interested readers, there is a book on the history of Markham written by Ken Wort and Mike Bennett and published by Merton Priory Press in 2005. (ISBN-10: 1898937648; ISBN-13: 978-1898937647)

NORTHERN POWERHOUSE

Although the company never stopped manufacturing major TBM components the observation by DavyMarkham management is that you need market confidence in your operation. As a result they do not intend to go back into supplying fully integrated DavyMarkham TBM's immediately. For the moment, as it did with the Channel Tunnel machines three decades ago, and DLR, the company will go into joint venture. This was initially to be with Robbins, but due to the recent merger between the US-based TBM manufacturer, NFM of France and NHI of China, it looks more likely that DavyMarkham will join up with the NFM side of the business for upcomming U.K projects such as High Speed Two (HS2). This is to keep in line with EU requirements.

PART OF SOCIETY

Clark sees HS2 as part of a wider push to consider socioeconomic factors in UK construction. The project is about linking the country together, and while this is going on there is a culture shift emerging in UK construction. Particularly with regards to linking local supply chains together, health and safety and environmental concerns.

"It's a sensitive subject, and wasn't very high on the list of priorities during the Jubilee Line," says Clark. "I think the reality is that in the civil engineering community there's a lot of decisions that are being made by project-oriented people without looking at the wider impact. And I think companies are trying to alter this now. There is an effort by the construction industry to understand the benefits of having a strong and healthy manufacturing industry.

"There is an interesting discussion as to whether the construction industry sees itself as part of the economy, or whether it is a service provider that presents a low-price solution when someone asks for it. A large chunk of what contractors take on is subcontracted, and the reality is that they don't fully appreciate the socio-economic impact of some of the decisions they make on training, apprenticeships, employment. Skills are lost as a result of short-termism. I think the increased emphasis that HS2 is bringing to these areas is welcome."

Clark argues that historically the UK manufacturing industry has been on the receiving end of some questionable decision-making. The privatisation of businesses that used to invest a lot of money and time training people has been wholly negative, in his view. Clark highlights the Central Electricity Generating Board, the water companies and British Steel as all being involved in fairly major investment and training schemes. This all stopped with privatisation. "And with it we have seen a general decline in the quality of capability, so it causes me a great deal of concern that I am a civil/structural/water engineer now at the helm of such an important engineering/manufacturing resource. But the reality is with more collaboration and the quality of people still in manufacturing, there is not a whole host of people saying we cannot succeed."

One of the things businesses in this sector can do to help themselves and wider industry, and something that Davy Markham is trying, is to reach out to look at where partnerships between engineering, manufacturing and academia can work together. For an example that isn't from tunnelling, take spent nuclear fuel casks. No one in the UK makes them, but DavyMarkham, and partners Nuvia and Sheffield Forgemasters, have the capability to design and manufacture them. So the company is looking at getting the design and manufacture together, and has picked up on 40 PhD students at the local Sheffield University studying nuclear waste.

What then takes place is a process of gently putting together R&D collaboration bids according to Clark. "However, the government needs to set the agenda for universities to collaborate more with industry to win investment."

LEVEL PLAYING FIELD

Further to the socio-economic concerns, and constituting a significant challenge to UK manufacturing, is artificial competition. While not looking for handouts, manufacturing in the UK is being hit by the heavy steel subsidies enjoyed by Chinese industry. This in turn feeds into manufactured components and false economies. Artificial competition.

Local stockists and local suppliers bring environmental benefits. Davy Markham's view is also that steel processes in Europe have far greater CO_2 awareness than steel processes elsewhere. "We need to see more transparency over pricing and cost in Europe. The subsidies we are seeing on imported steel need to stop. If other European countries are buying this steel, how is it ok to gain that advantage?"

If the client writes CO_2 requirements into tenders, it can galvanise the supply chain and makes people see they are part of the bigger picture. "The debate is not just about plate. That misses the point of the argument over steel. It is about everything that the subsidised steel is then used to create."

FURTHER CHALLENGES

As for more general challenges that DavyMarkham will face re-entering the industry as an active manufacturer, Lindley believes that in the past there has been an over dependency on one manufacturer, however alternative suppliers are being selected for upcoming U.K projects such as Tideway and the Northern Line Extension demonstrating a more open attitude in the market. "It will be a challenge convincing the HS2 consortia groups that Robbins/NFM designed machines can be supplied out of the U.K, but we have the advantage of localised service and support and we have already started our preparations with the strong local supply chain. "

Clark concludes: "It's a funny old world this business of ours. There's an overlap between TBM manufacture and EPC. How do you actually differentiate the different critical success factors that go with construction, and how different are they to manufacturing. The truth is they are very, very similar. Except for the fact that in manufacturing, you are working on a site that you control all the time. "A key part of it is bringing together all the different pieces of the puzzle: different perspectives, standards and cultures for the final product. We are a projects business and need to get the engineering right, the project management right, and the supply chain right. The way we hope to differentiate ourselves is by being more flexible, more adaptable than our competition. More focused on what people want rather than presenting one way of doing things."

It should be noted that TBM manufacturers have historically enjoyed success when sold to companies able to focus on the industry and make quick decisions in a risky environment. When managed from a distance or centrally, the reverse has been true in several well-known instances

History of Davy Markham

For most of its history, which spans nearly two centuries, Davy Markham was two separate entities: Davy and Markham.

DAVY

From leasing his first Sheffield workshop in 1830 David Davy's business grew and Davy Brothers Ltd was formed in 1837. In the 1840's they built six steam locamotives one of which completed the first Sheffield to London passanger sevice. By 1880's Davy Brothers were building 5,000t presses and at the turn of the century they were capable of constructing enormous 12,000 HP steam engines. By the 1950's, serving the steel industry demanded a large engineering design office.

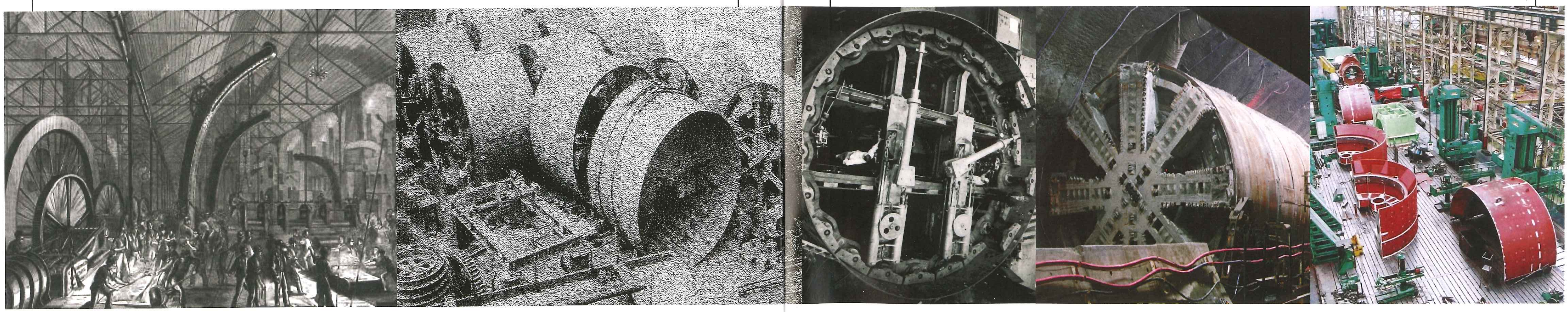
MARKHAM

In 1885 Charles Paxton Markham bought a Chesterfield foundry from William Oliver, establishing Markham & Co. Winding engines for the coal mining industry were Markham's main product. During the great depression of the 1930's Markham diversified supplying 20 winding engines into the South African gold mines. By 1948 Markham had built over 200 steam and electric winding engines for both the home and export markets. Markham took advantage in the construction of both the London and Moscow underground systems, supplying 58 shields between 1890 and 1900 and a further 77 shields between 1900 and 1932. A substantial portion of these were full face machines, long before any other modern TBM supplier was making full-face machines. These were the famous Price machines which were responsible for the majority of the London Underground excavation in that era. In 1937 the first of four 9.8m shields was constructed for the Dartford Perfleet Tunnel. In the 1980's Markham manufactured the two 8.36m TBMs for the Channel Tunnel seaward running tunnels and then Surry, EPB, Rock and Open face TBMs for projects worldwide.

DAVY MARKHAM

When both Davy and Markham came under the same parent group, Kvaerner they amalgumated in1998 closing the Markham Chesterfield works. Markham engineering expertise specilising in Tunnelling, Mining, Moving Bridges, Power Generation in both water and nuclear joined with Davy expertise suppling equipment to the steel industry and its workshop facilities. Regarding TBMs in recent years its activities have been limited to manufacturing and exporting large TBM components.

Tunnels & Tunnelling would like to thank Richard Lewis of YL Associates for his assistance with this article



Below (left to right): ***Davy workshop in the 1850s; early Markham shield production at the Chesterfield factory; Dartford Purfleet Tunnel TBM; Channel Tunnel TBM; Davy Markham works***

ELECTION YEAR

Tunnel work in the US has seen support from voters in some local elections and possibly more this November. **Nicole Robinson,** editor of *Tunnels and Tunnelling North America* highlights tunnel projects across the country

WITH A PRESIDENTIAL election looming this autumn, the forecast for federal funding for infrastructure is somewhat uncertain. Too often infrastructure is among the issues drowned out by so-called moral issues and vague discussions of the economy.

Though project decisions and planning fall mainly to local governments and agencies, they often rely in part on federal funding. The two main presidential candidates have shared their plans for infrastructure development (see box), though in general both seem to fail to inspire voters.

This spring the Underground Construction Association (UCA) of SME hosted the World Tunnel Congress (WTC), in San Francisco. It was the first time in 20 years for the event to be held in the US, and marked the largest gathering of tunnel professionals in history. The consensus among industry leaders from across the US is that tunnelling has a lot to offer and will remain active. Much of the work currently underway or in the planning stages is related to transit, water and wastewater.

MEASURE UP

Bill Hansmire, technical director of tunnelling for WSP Parsons Brinckerhoff, says "today Los Angeles has changed from being what you might perceive as highway-centric."

Local highways such as the San Bernadino and the Santa Monica freeways have notorious traffic congestion, with which the city has had enough. In 2008 residents voted to approve a tax measure to fund more transit.

"Not just entirely rapid, but all forms of transit that work together," Hansmire explains. "A lot of that is tunnels.

"Today there are major tunnel projects underway and these tunnels form what I think is the keystone. You can have lines coming up from the suburbs into the city but if they can't get through the urban core, no one is going to take them."

There is approximately USD 10bn in construction right now to build another 10 miles of underground transit, "and this 10bn will make a real difference," he says.

He's working on the Regional Connector – a 2-mile (3.2km) tunnel with three stations that will connect Los Angeles' Blue and Gold Lines. The TBM should launch before the end of the year on this USD 1.5bn project. There is a TBM working on 1 mile of twin tunnels for the 8.5-mile (13.7km) Crenshaw/LAX light rail line, which includes three underground stations. There is also the three-phase, 9-mile (14.5km) Westside Subway Extension of the Metro Purple Line, estimated to cost USD 5.6bn. A JV of Skanska-Traylor-Shea, with lead designer Parsons Transportation Group, is the design-build contractor for the USD 1.6bn first phase of 3.9 miles with twin tunnels and three underground stations.

In November Los Angeles County will vote on another ballot measure for a half-cent sales tax increase to fund a major expansion of Southern California's transportation infrastructure. Called one of the most ambitious in modern US history, the tax increase would generate at least USD 860M per year for street repairs, highway improvements and new rail construction.

The tax, which has no end date, would increase the county's base sales tax rate to 9.5 per cent and push the rate to 10 per cent in some cities. If the tax were approved, two cents for every dollar spent in the county would fund transportation improvements. It will require a two-thirds' vote to pass.

Nicole Robinson
Nicole is based in Minneapolis, Minnesota and covers the North American market

The candidates' take

HILLARY CLINTON: UP TO USD 500BN

Plan: Clinton would increase federal infrastructure funding by USD 275bn over a five-year period, fully paying for these investments through business tax reform. Of these funds, she would allocate USD 250bn to direct public investment. She would allocate the other USD 25bn to a national infrastructure bank, which would leverage the funds to support up to an additional USD 225bn in direct loans, loan guarantees, and other forms of credit enhancement. Clinton estimates this infrastructure plan could result in up to USD 500bn.

She specifically mentions public transportation, passenger rail and water and wastewater systems.

DONALD TRUMP: USD 800BN TO 1TR

Plan: Trump said he would double Clinton's infrastructure spending by creating an infrastructure fund with a low interest rate and selling bonds to investors.

His only specific infrastructure concern at the time of publication is a wall between Mexico and the US.

WATERWAYS

This summer saw a milestone on the bottom of the Elizabeth River in Virginia. The Elizabeth River Tunnels Project Team, comprised of Elizabeth River Crossings OpCo, LLC, SKW Constructors, JV and the Virginia Department of Transportation (VDOT), opened one lane of the new, one-mile long, immersed Midtown Tunnel. Connecting the shorelines of Portsmouth and Norfolk, Virginia, crews immersed 11 elements, each made of 16,000t of reinforced concrete, starting in October 2014 and placing the final one last July. The two-lane road tunnel is part of the largest design-build project in the Hampton Roads region's history. Hampton Roads refers to the area in the middle of the Eastern seaboard where the James, Nansemond and Elizabeth rivers pour into the mouth of the Chesapeake Bay. Some 1.6 million people live locally and rely on Virginia's existing Midtown Tunnel, which carries more than one million vehicles per month.

Chesapeake Bay will also be the site of a new bored tunnel: the parallel Thimble Shoal Tunnel Project will construct a new mile-long (1.6km), two-lane tunnel under the Thimble Shoal Channel. The new tunnel will carry two lanes of traffic southbound and the existing tunnel will carry two lanes of traffic northbound.

This summer the Chesapeake Bay Bridge-Tunnel (CBBT) awarded a contract to the design-build team of Dragados USA and Schiavone Construction Company, LLC, which submitted the lowest price proposal at USD 755,987,318. The JV bid the project as a TBM-mined tunnel, which will have an inner diameter of 39ft (11.9m). Maximum tunnel depth from the crown will be 105ft (32m) below the water surface and, and from the invert, 134ft (40.8m) below the surface.

MEETING URBAN NEEDS

Verya Nasri, gobal tunnel lead with Aecom, gladly reported at WTC that phase one of the largest infrastructure project in the US, has been executed on time and on budget with no major claim. The four-phase Second Avenue Subway is worth an estimated USD 17bn. Underground for their entire 8.5-mile length the Second Avenue Subway's twin tunnels would run between Harlem in the north and Hanover Square in the south.

The first phase reaches completion this year, which is worth USD 4.5bn. He says of the project's success, "it's maybe not very common but it's possible if the project is planned well; if we have a good partnership between the main players, owners, engineers, contractors; if we have good public relations and outreach with the community; and if we coordinate well from the beginning; then a large project like this can be successful even in the most difficult environment in the world."

He's speaking specifically of New York's Upper East Side, "one of the densest urban environments in the world, probably the richest area in the United States, and being the place with the highest concentration of lawyers," he jokes. "The importance of this particular project is that the only way you can build it is to tunnel. There isn't any other solution."

To meet the needs of the country's largest metropolitan region tunnel projects are delivered not just for transit but also for water–through the New York City Department of Environmental Protection (DEP). In particular it has a program to repair the Delaware Aqueduct's Rondout-West Branch Tunnel. A bypass tunnel and two deep shafts are currently underway. Schiavone Construction Co. LLC, began work in 2013 on a contract to excavate two 30ft diameter shafts of 700ft and 900ft at each end of the tunnel alignment – one in the town of Wappinger, to the east, and one in the town of Newburgh, to the west. A JV led by Kiewit is using a TBM to mine the 12,500-long tunnel in rock.

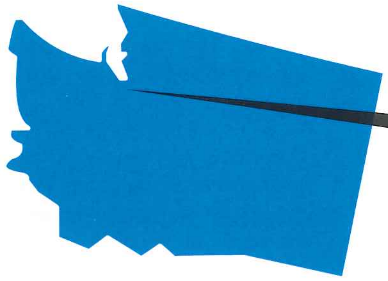
Above: ***New York's Second Avenue Subway***
PHOTO: MTA PATRICK CASHIN

Opposite: ***Planned and current transit projects in LA***

CLEANING UP

In Indianapolis a recent economic impact study commissioned by Citizens Energy estimates that the utility provider will invest more than USD 4bn in its water, wastewater and natural gas systems from 2011-2025. The study estimates these investments will create or support 58,000 jobs in Indiana that will generate more than USD 450M of state and local taxes.

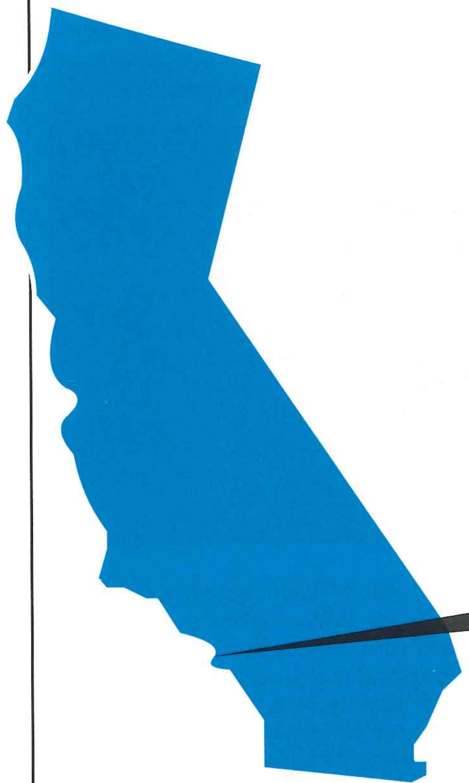
A large part of this is the DigIndy tunnel system, a 200ft (61m) deep, 28-mile (45km) network of sewers, 18ft (5.5m) in diameter. So far 10 miles have been excavated, and a JV of Shea/Kiewit secured a USD 500M contract this spring to complete the final 18 miles. The TBM is expected to re-launch this autumn



Seattle, Washington

Contractor Seattle Tunnel Partners (a joint venture of Dragados USA and Tutor Perini Corp) completes sections of the SR 99 tunnel's top, southbound roadway deck. Crews are building the double-decked roadway behind the TBM this summer.

PHOTO: WSDOT



Los Angeles, California

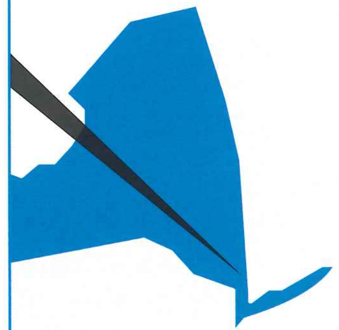
The 6.5m diameter Herrenknecht TBM mining rail tunnels for the Crenshaw/LAX line broke through the station box for Martin Luther King, Jr. Station on August 22. Walsh/Shea Corridor Constructors (Walsh, Shea, HNTB, Comstock and Arup) is excavating 1-mile (1.6km) twin tunnels.

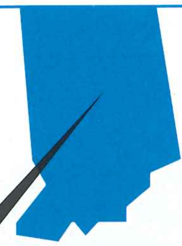
PHOTO: JUAN OCAMPO FOR METRO

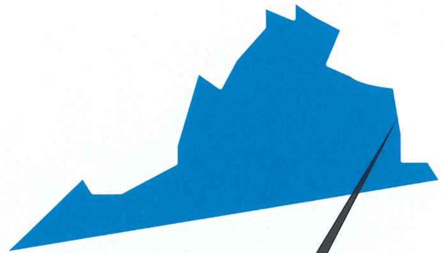
Newburgh, New York

A TBM will mine between two shafts of 700ft and 900ft depths for the 2.5-mile Rondout-West Branch Bypass Tunnel along the Delaware Aqueduct. Upon completion, DEP will drain and repair leaks in the Rondout-West Branch tunnel..

PHOTO: NYC WATER







Indianapolis, Indiana

Citizens Energy Group awarded a USD 500M contract to J.F. Shea and Kiewit this spring, to complete the current tunnel contractor, to complete the remaining 18 miles (29km) of tunnel and drop shafts. The refurbished TBM is launching this autumn.

PHOTO: ROBBINS

Chesapeake Bay, Virginia

A barge takes borings in the Thimble Shoal Channel for the 1-mile (1.6km) long bored tunnel, to be built by Dragados USA and Schiavone Construction Company, LLC. The new parallel tunnel will add two traffic lanes for the north-south route.

PHOTO: CBBT

OSLO FOUR

Two 20km tunnels are underway for the highspeed Follo line project, Norway's biggest scheme and one of the largest in Europe. Report and pictures by **Adrian Greeman**

Adrian Greeman
Is a former editor and long-standing regular contributor of *Tunnels and Tunnelling*

A 9.96M DIAMETER hard rock TBM began grinding its way out of its big assembly chamber south of Oslo in September heading northwards to the capital. Next month its partner will begin a second parallel bore through the hard gneiss. In November and December respectively, two more machines start out southwards. The clutch of four Herrenknecht machines have been assembled in one place, a complex of caverns blasted out at the Åsland construction worksite site halfway along the 18.5km drive through the highland area south of the city. It runs parallel to the inner part of the Oslo fjord which curves south from the city waterfront. The three year excavation programme for the machines is the main part of the largest infrastructure scheme in Norway, a new NOK 25bn (USD 3bn) high speed rail link to the rapidly expanding town of Ski and its large and growing commuter population. Potentially and eventually the line will go onwards as a high speed link into central Europe. Trains will run at 250km/hour in the tunnels.

EVERY TYPE OF TUNNELLING

As well as the main TBM section, unusual in a country that more often works with conventional excavation methods (more on these methods below), there is plenty more going on in a project which includes virtually every type of tunnelling on its overall 22km length. Planning and design has been underway for four years and construction began last year on the conventionally bored sections and site works.

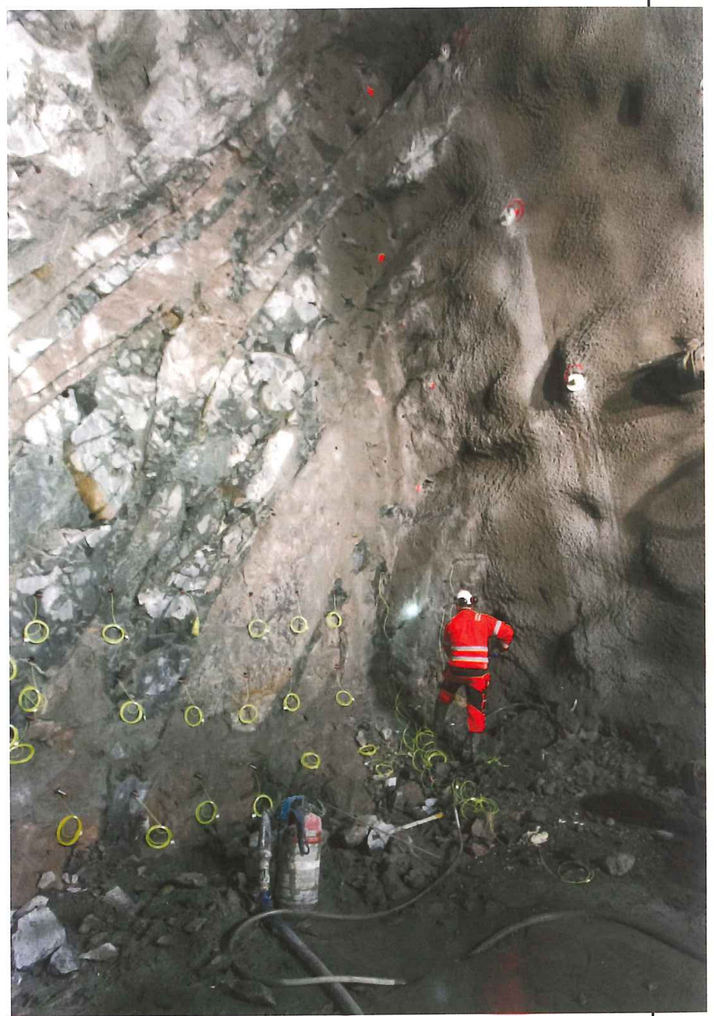
This work is mainly for a final 1.5km of the main tunnel section. It cannot be done by TBM because of difficulties threading the bores through the steep Ekeberg hillside close to the capital. A whole spaghetti of other tunnels has to be passed through and awkward widenings and transitions are needed too. There is an additional short tunnel for another local line to be added in as well. Some 64km of new track will be created for the whole project.

Some of this conventional work has been using the first European application of drill and split wedge rock excavation.

An equally complex set of approach tunnels, branches to access points and starter caverns was also completed earlier this year for the important central Åsland site, again requiring conventional means. There will also be a complicated cut and cover tunnel running a length of 700m from the Oslo main station through the soft ground around the old harbour. This will take a series of new lines from the remodelled main station underneath the former medieval city area which will be restored around new parkland.

"You can see we have all kinds of challenges on the project" says Anne Katherine Kalager, overall project manager for the client, Norway's state railway company Jernbaneverkert.

The cut and cover is a major project in itself, carrying up to six parallel lines which draw together the tracks and points which interface with the nineteen tracks between platforms in main station. For the moment this cut and cover work is on hold because of major archaeological works which have run over four summers so far, making critically important discoveries about the city's past. "It has meant re-writing much of previously understood history" says Kalager.



***Above:** Work on the Follo Line as Tunnels and Tunnelling visited in June 2016*

QUICK CLAY

When it is finally built, the excavation on low ground close to the waterfront will have to handle difficult unstable ground, so called "quick clay". Formed during a marine period this was originally laid down as a clay-salt matrix, she explains, "but then as the sea receded the soluble salt was washed out." That leaves voids between the remaining clay particles "which are stacked like a house of cards and just as collapsible" she says. A huge amount of ground stabilising soil mixing will be needed using lime and cement before building the concrete box tunnel structures.

The same is true near to Ski for the cutting approaches and works on the new three platform six track station. "Like the Oslo end, it all has to be done close to live tracks, keeping the existing trains running."

EXISTING INFRASTRUCTURE

Perhaps the most complex works so far have been the tunnels into the Ekeberg, a steep hillside escarpment rising on the south side of the city. Its side slopes are prime residential areas with houses offering an excellent view across the stunning fjord vista and the city centre, with its newly developed waterfront area including the gleaming white wedge of the new opera house. The housing is obviously sensitive to vibration and damage.

Just as significantly Ekeberg has roads and incoming rail tracks running along the narrow fjord edge and a network of existing tunnels inside the hill itself. Some of these date back decades and some are relatively new, including three parallel road tunnels built in the 1990s and two more added in the last decade for the interchange and underground approach works to the new cross harbour immersed tube tunnel.

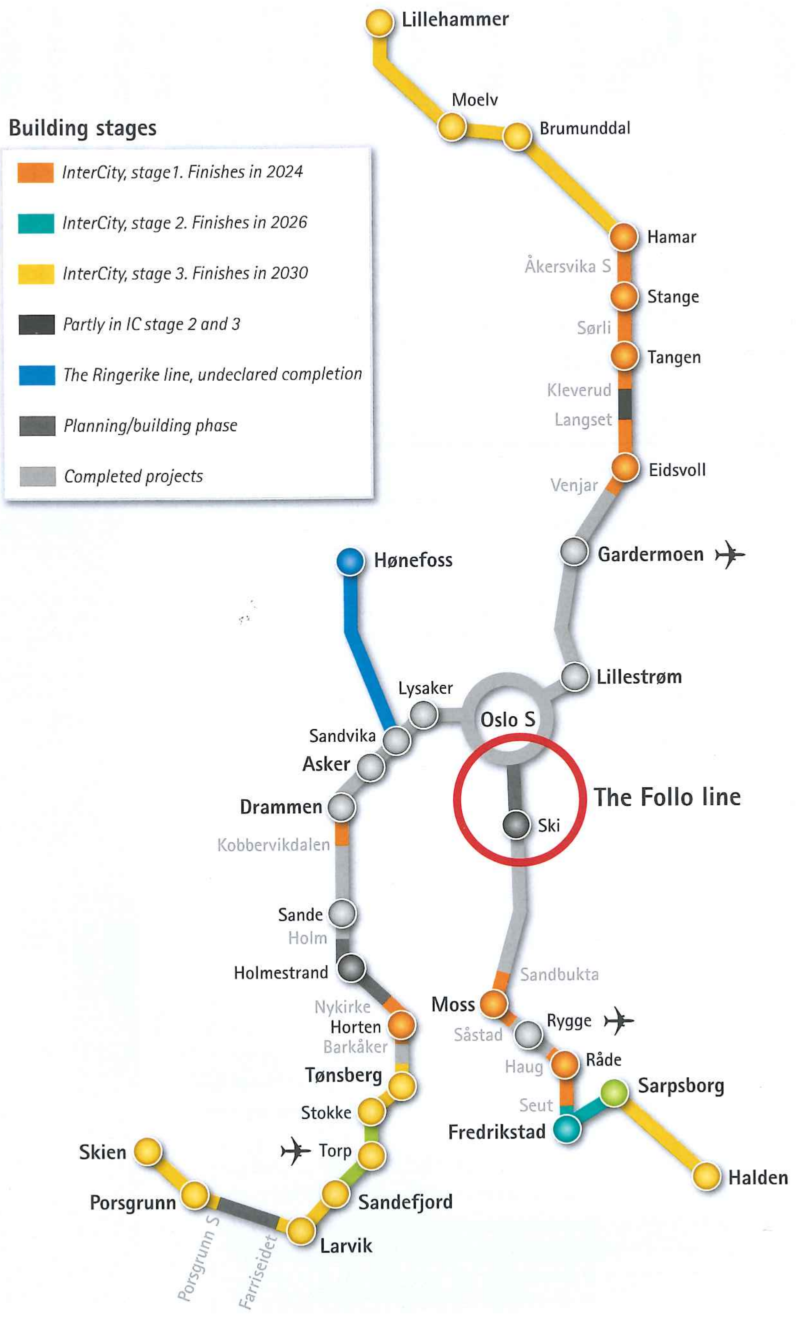
The latter tunnels had their own issues when they crossed near to the existing road tunnels and at one point include an underground bridging structure over an existing bore.

There is also a river diversion tunnel dating to the 1920s which runs across the alignment carrying water from the Alna river out of the city centre and, a bit further south, a complex of underground storage caverns for oil and their access approaches. These caverns are used by a variety of oil companies and at one time were supplying approximately 50 per cent of Norway's oil consumption. They include storage for aviation fuel feeding the main airport north of the capital. They also include an access tunnel with services and electrics.

Completing the picture are two major sewer tunnels which carry city waste to a big underground processing plant.

"You can see why we call it a spaghetti," says Adler Enoksen the client side project manager for this section of the work. "And there is more we think, military tunnels though we are not told where those are; the state forces have looked at the plans however and say they are not affected."

Through the tangle the project has to thread the incoming main bores and an additional bore heading out towards the fjord side; this latter connection will carry one of the tracks for the existing Østfold



Line to Ski, which has to be realigned to link into the new tracks into the station.

As well as the main bores a whole series of access adits for the work have to be made as well. Also some of the main tunnels have to be larger caverns, widening out to accommodate track junctions and divergences.

"And there is possibly a new 500m long bypass tunnel section

needed to take the river tunnel past the new complex" says Enoksen "which then also requires an extra adit. But that is not decided yet and we may do a relining and strengthening of the existing river tunnel instead."

If the latter is chosen the work can be done in winter when river flow is low.

Challenges for the project include the logistics and sequencing of the work. The contractor for this section, Italy's Condotte D'Acqua has to operate from a single narrow and highly constrained site on a narrow strip of land between the fjord edge road and railway and the steep hill slope. Spoil is taken out from here by trucks which then have only a short journey to a harbourside quay where barges take most of it away.

For the actual excavation there are further challenges. One is a thin layer of alum shale on the mountain slope, about 50m thick. A frequently met geology in Scandinavia this is a variety of black shale containing pyrite which can form sulphuric acid, when weathered and which acts on other constituents to form alum.

But it is problematic because it also contains algae organics and "is rich in aromatic hydrocarbon attributed to post-depositional irradiation damage induced by uranium concentration. It also can contain radium as gas a result of uranium decay".

"We have experience in mitigating its effects in various Norwegian projects and probably the main issue will be to ensure sufficient ventilation" says Enoksen, adding that the shale has not yet been reached. He does not think protective suits will be needed.

It will require special disposal however, probably at a specialist site 100km southwards. "There is only some 30 000t likely to need removal but it is an expensive business."

SOFT TOUCH

That is to come. Work so far, begun last year, has other problems to contend with, namely vibration noise or damage. As well as not disrupting the well-off neighbourhoods above, this is important because of possible damage to existing tunnels and the underground bridge structure. Rock cover between tunnels in a few areas is just a few metres.

Consultations are needed with concerned operators says Enoksen and limits have to be set very carefully for blasting, with restricted round lengths in many areas.

The project is also trying out for the first time the rock splitting technique, developed initially in Japan. In this hydraulic wedges are used literally to split the rock. They work much like the ancient "feathers and wedge" used in quarries from Egyptian times onwards where two inclined "feathers" are driven apart by a hammered central wedge.

The technique requires a relatively precision drilled rockface, to ensure straightness of the boreholes and they have to be placed much more closely than for blasting, down to 400mm apart. Usually, according to a research paper done for the Norwegian University of Science and Technology in Trondheim by Jens Anders Brenne Volden, the drill hole length will be no more than 1m.

A drill pattern is needed which creates an initial starter space for the rock to split into, usually a short line of adjacent boreholes.

The wedges used on the project are so-called Superwedges, from Italian firm Ripamonti. They are excavator mounted and driven by hydraulic takeoff.

The system is proving good at reducing vibration but it is obviously very slow compared to even restricted blasting says Enoksen. He says the length of tunnel to be done this way has been shortened. "In the beginning it was about 1km of tunnel but we have been able to reduce it over 50 per cent by agreement with some of the neighbours for slightly different vibration limits.

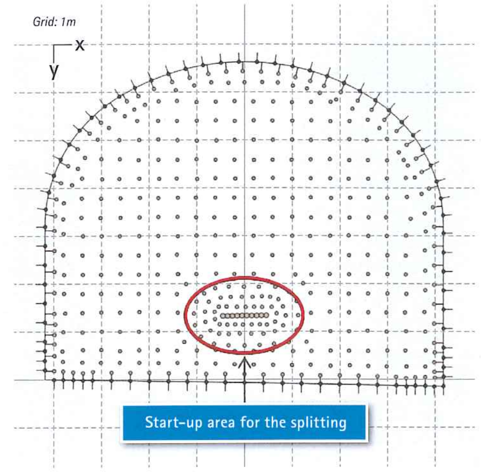
"The contractor has been keeping detailed blasting records of actual vibrations which allow renewed discussions." Condotte is highly experienced in the difficult and unstable tunnelling

Left: ***Map view of the Follo Line and surrounding infrastructure***

Left, below: ***Approximate breakdown of drill and blast and TBM works***

Right: ***Rock splitting drill pattern***

Below: ***TBM assembly in the cavern***



conditions often found in Italy which helps.

Once the limits are determined for blasting, mostly around 1m to 2.3m rounds with a maximum of 4.2m, the actual work is relatively straightforward in the hard granitic gneiss which prevails for most of the route. There are some dykes and igneous intrusions to look for but mostly the rock is stable and hard.

"Support is shotcrete and there is some rock bolting" says Enoksen. In some places the rock is pregrouted if water is detected by regular advance boreholes. These are done as 24m long holes every

15m of tunnel advance," says client site engineering geologist Marcus Fritzøe Lawton "and we also log parameters like penetration rate, feed pressure and rotation speed to get an idea of rock quality ahead.

Occasionally there is more complex pressure test drilling involving core drilling. This is needed to determine rock stress patterns for 3D modelling purposes in areas of particular difficulty. "We have done this in three locations" says Lawton "using the firm Sintef".

Spoil is loaded by Caterpillar loaders onto standard trucks. It is high quality rock and has been sold to local suppliers who use it for concrete.

While this work has been underway, major drill and blast excavation was also underway at the main central site. This is a point halfway along the main drives in an area of the highlands where the housing density is reduced.

"Overall the district is quite well populated" says Kalager. It was for that reason most of all that the TBM method was selected for the main tunnels she says. Usually in Norway with its stable hard rock, conventional drill and blast would be used, especially as the local tunnelling industry is probably one of the most experienced worldwide in these conditions. "TBMs were used for hydro works in the 1980s and one northern project recently but have not seen much use for infrastructure" she says.

"But conventional methods would have needed half a dozen access points for a project this size meaning disruption of residential areas. And they would have had access only onto local roads" she explains.

TBMs can also install a precast lining as they go, saving on follow on works. The lining is not needed for support but for preventing water ingress, particularly important in a cold climate. "We are aiming for a watertight tunnel as a success criterion" says Kalager.

At Åsland a big enough area was available for a compact but large main site of 250,000m², with the added advantage it was virtually alongside the main north-south E5 road route to bring in equipment and remove spoil. Enough space was there to build segment factories and an additional 160,000m² area to stockpile some of the eventually 11Mt of spoil the bores will produce.

But conventional methods have been used to prepare what Kalager describes as a "whole complex of access tunnels and caverns". In a pre-contract Norwegian firm AS has worked on that, driving two 1km long access tunnels and end branches, a half kilometre section of the main tunnels and two large assembly chambers for the TBMs. The underground complex is slightly different to the single chamber assembly area envisaged by the project designers she says. Local consultants Multiconsult and Swiss firm Amberg make up the design team and put forwards a proposed design but the five main contracts on the project are all design and construct "and it is up to the contractor to choose the detail."

The issue is an important one she says as it is part of a series of complex decisions needed for efficient logistics on a site which has to provide for the entire 18.5km drive from one place. Her client side team has worked closely with the contractor on this.

An additional question is for the tunnels' final operation. The site will become the location for a safety refuge and evacuation system for the tunnels, similar to the emergency stations on the Gotthard, Koralm and other long high speed rail tunnels.

"At 'just' 20km compared to say Koralm's 32km or Gotthard's 57km we do not legally require a safety station" says Kalager. "But it makes sense to use these points since they have been excavated, and we are considering a design at present."

Permanent safety measures will also include cross passages between the bores where passengers can evacuate to the opposite tunnel in the event of fire or other accidents.

For the main drives, the Spanish-Italian JV of Acciona Infraestructuras and Ghella, opted for two assembly caverns for the TBMs. They are each 22m high, 24m wide and 54m long and are linked by a 450m section of enlarged main drive tunnel between them where the backup trains are put together.

It was in these caverns that the TBMs were put together once the components started to arrive in the Spring from Herrenknecht's factory in southern Germany. Dutch lifting firm Mammoet has worked with the contractor and the TBM maker on the assembly, using a big 500t capacity strand jacking lift rig inside the cavern.

WORK IN PROGRESS

The first machine was taking shape at midsummer when Tunnels and Tunnelling was able to visit the project and the second was being readied. All four have progressed well since.

Elsewhere on the site a mass of facilities were being readied too, most particularly a factory for three segment production lines using forms from CBE Group. The tunnels use a seven segment ring for a lining and additionally the factories will make an invert section to provide a flat road surface in the tunnels.

The 400mm thick gasketed segments will be delivered to the machines using rubber tyred multi-service vehicles, says Kalager. "The team examined a rail system but the access tunnel gradients are too steep for that to run to the outside and it would have meant carrying segments into the tunnel for re-loading."

For safety and logistical reasons it made more sense to use the segment carriers. Additionally there is no need for spoil trains as, like most modern tunnels, a conveyor system is being fitted. Long conveyors from Swiss supplier Marti for the tunnels will discharge onto a shorter 500m conveyor to the surface where a big stockpiling area makes up part of the site.

Spoil will be partly re-used for the segment concrete batching plant, perhaps around 15 per cent and the project has drawn on experience from other recent tunnels to work out the best methodology. In particular it visited Gotthard in Switzerland and the Koralm tunnels in Austria.

Some 15 per cent of the spoil will be used this way and much of the remainder is likely to be removed by truck to be used for reclamation and land creation for port works. There are also on-site living facilities at Åsland for some of the up to 800 workers who be on the project at its peak point once the TBMs start their drives in earnest. First of the TBMs began its drive at the beginning of September, initially testing systems and bedding in the crews, and full production should be underway on all the four drives in January with a hoped 12m to 15m daily progress

STRUCTURAL STRENGTH

Safeer Abbas, assistant professor, Civil Engineering Department, University of Engineering and Technology, Lahore, and **Moncef Nehdi**, professor, Department of Civil and Environmental Engineering – Western University, report on mechanical and durability performance of precast tunnel linings

THE LINING SYSTEM in tunnel infrastructure is very important as it provides the first line of defense against overburden loads and complex geotechnical surrounding conditions. In this study, conventional reinforced concrete (RC) and steel fiber-reinforced concrete (SFRC) precast tunnel lining (PTL) segments were investigated for mechanical and durability properties.

Full-scale RC and SFRC PTL segments were tested under a loading configuration that simulates in-situ conditions. Moreover, salt ponding and rapid chloride ion (Cl-) permeability tests were conducted on cylindrical cores retrieved from the RC and SFRC PTL segments to assess corrosion potential.

Results showed that the SFRC segment exhibited higher cracking load and more stable post-peak behaviour compared with the conventional RC segment. Furthermore, the SFRC segment exhibited higher resistance against Cl- ingress than that of the RC. These experimental results indicate structural and durability benefits of SFRC PTL segments supporting their increasing full-scale applications in tunnelling projects.

INTRODUCTION

The applications of PTL in tunnelling technology are increasing due to its proficient and cost-effective installation process compared with the conventional in-situ lining technique (Elliott, 2002). PTL can act as a preliminary as well as final support for carrying the complex surrounding loads. It is suitable for both soft and hard ground (Hung et al. 2009). PTL segments are usually installed through a TBM in the form of a circular ring (De Waal, 2000). The advantages of PTL include: removal of ancillary work, speedy construction, superior quality, less material waste and fewer maintenance costs (Hariyanto et al. 2005).

Conventional reinforcement corrosion and its associated detrimental effect is the most serious issue facing engineers. Failures of the Berlin Congress Hall and a parking garage in Minnesota were the consequences of concrete corrosion (Isecke, 1983; Borgard et al. 1990).

Along with surrounding environmental conditions, inappropriate use of construction materials, concrete properties and inadequate construction practices are the main contributing factors that aggravate the corrosion process (Amleh, 2000). The corrosion of reinforcement costs around CAD 3bn (USD 2.29bn) per year for structural repair in Canada (Davis, 2000). Likewise, the US spends approximately 1 per cent of its gross domestic product for corrosion-associated rehabilitation works (Whitmore and Ball, 2004).

SFRC is a novel material for PTL segments, which improves the structural and durability properties. SFRC can completely replace traditional reinforcing steel cages (Plizzari and Tiberti, 2006). Various tunnel projects around the world have used SFRC such as the Second Heinenoord Tunnel, Netherlands; the Madrid Subway, Spain; the Channel Tunnel, UK and the Bright Water Sewer System Seattle, US (King and Alder, 2001; Woods et al. 2003; Kooiman et al. 1998). The dispersion of steel fibers into PTL segments limits the growth and propagation of cracks during the assembling, curing and handling process at the fabrication plant. This preserves the mechanical integrity of PTL segments.

Furthermore, steel fibers do not corrode in the same way as large steel rebar does, due to the discontinuous dispersion in the mixture, which does not allow the continuous onset of corrosion (Granju and Balouch, 2005).

Also, the crack bridging phenomena of fibers restrict the penetration of Cl- inside the concrete compared with plain concrete (Balouch et al. 2010). This results in improved durability properties of SFRC.

In this study, the mechanical and durability performance of RC and SFRC PTL segments were investigated. These segments were fabricated for the Toronto-York Spadina Subway tunnel extension project.

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Table 1. Mixture composition for RC and SFRC PTL segments

Materials	Normal concrete*	SFRC*
Cement	1.00	1.00
Hydraulic slag	0.49	0.49
Fly ash	0.43	0.43
Silica fumes	0.11	0.11
Coarse aggregate	2.82	2.76
Fine aggregate	1.76	1.76
Steel fibres	0.00	0.11
Polypropylene fibre	0.003	0.003
Water	0.59	0.59

Source: Authors
**Quantities are in mass/cement mass*

RESEARCH SIGNIFICANCE

Normally, the Toronto Transit Commission (TTC) designs PTL segments using the conventional steel rebar reinforced concrete. The TTC aims for a service life of at least 100 years with minimum maintenance issues. But every year the TTC spends a huge amount for tackling corrosion associated durability issues. It has been found that the complete elimination of the reinforcement cage is a direct and efficient way of handling this issue.

SFRC is a highly potential material, which allows the entire removal of conventional reinforcement cages in PTL segments. Moreover, the complete removal of conventional steel reinforcement cages from the PTL reduces the cost and effort in fabricating these curved shape cages with complicated welding and detailing. Findings of this research will lead to better understanding for the mechanical and durability aspects of SFRC PTL and pave the way for wider implementation of SFRC in tunnel lining systems.

MIX DESIGN AND SPECIMEN PREPARATION

Two different types of segments were investigated: RC and SFRC without any conventional rebar reinforcement. The concrete mixture design used for casting RC and SFRC were identical except the addition of steel fibers for SFRC segments. Table 1 shows the mixture design.

Samples used for performing the durability tests were cored from the RC and SFRC PTL segments. The coring process was done according to ACI 214.4R guidelines (Guide for Obtaining Cores and Interpreting Compressive Strength Results). The retrieved cores at the surface are referred to as 'exposed', while inner cores are referred to as 'internal.'

The flexural test setup

TESTS CONDUCTED

Flexural test

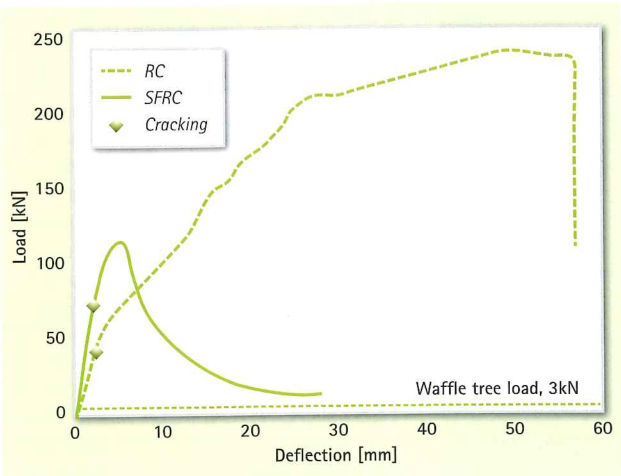
The flexural test used skewed edge precast segments that measured 3,180mm in length, 1,500mm in width and 235mm in thickness. PTL segments were simply supported on a reaction frame. A mid span load was applied on the PTL segment using a waffle tree loading frame (Caratelli et al. 2011). A rubber bearing pad was placed in between the PTL segment and the waffle tree loading frame in order to smooth the contact surface. A mid span deflection was monitored using three linear variable displacement transducers (LVDTs).

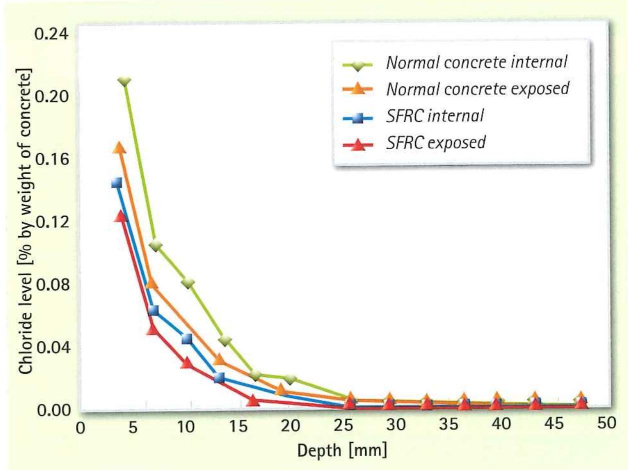
Salt ponding test

The penetration of chlorides inside the cored RC and SFRC specimens was determined using a salt ponding test in accordance with AASHTO T259 recommendations (Standard Method of Test for Resistance of Concrete to Chloride Ion Penetration). Three cored specimens from both exposed and internal surfaces of RC and SFRC PTL segments were evaluated for its concrete quality.

Specimens were 100mm in diameter and 75mm in thickness according to a previous study (McGrath and Hooton, 1999). The perimeter of the specimens was layered with epoxy and coated with duct tape. The height of 3 per cent salt (sodium chloride (NaCl)) ponding solution from the specimen's top surface was 12 to 15mm. All the specimens were stored at 40C in order to accelerate the chloride penetration. After 90 days of salt ponding, the chloride content versus penetration depth was determined.

At the end of the desired age, approximately 10 grams of concrete powder samples were collected from the tested specimens along the depth from the top surface at intervals of 3mm for the determination of chloride contents according to FHWA-RD-72-12 guidelines (Sampling and Testing of Chloride Ion in Concrete).





Top left: **Figure 1, Load-mid span deflection for RC and SFRC PTL segments**

Top right: **Figure 2, Chloride profiles for normal concrete and SFRC**

Left: **The RCPT test apparatus**

Below: **The coring process**

Rapid chloride ion permeability test

The study used the ASTM C1202 (Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration) for a rapid chloride ion permeability test (RCPT). This test requires six hours to complete and is also referred to as a short term corrosion performance test (Hooton and Thomas, 1997).

Exposed and internal cored specimens from both RC and SFRC PTL of the size 100mm in diameter and 50mm height were tested for their electrical resistance ability of chloride ions. Specimens were sufficiently dried in a dessicator after an epoxy coating on their circumference. Afterwards, the cored specimens were saturated with water for 18 hours before being placed in an RCPT apparatus. The left side of the RCPT cell contains 3 per cent NaCl while the right side has a 0.1N sodium hydroxide (NaOH) solution. The observations (i.e., number of coulombs passed) were recorded after every 30 minutes up to six hours.

RESULTS AND DISCUSSIONS

Structural performance

Flexural response of RC and SFRC PTL segments was expressed as load-mid span deflection shown in Figure 1. All LVDTs at mid span showed similar deflection corresponding to applied loads describing the absence of torsion effect (Caratelli et al. 2011). The load in Figure 1 showed the actual load capacity of the segments in addition to self weight of the waffle tree loading frame.

Load-mid span deflection behavior of RC PTL segment can be divided into three phases (Figure 1). Initially, the slope of the curve remains constant showing the elastic range. At a load level of 45 kN, cracks started to appear and phase 2 began. At this point, the slope of the curve became steeper up to the yielding point (210 kN).

Lastly, the load carrying capacity of the segment continued to increase and reached the ultimate load at 244 kN. Afterwards, a sudden drop in load was observed with a brittle failure of the segment. No post ductility (nor descending branch) behavior was observed after the peak load carrying capacity.

On the other hand, the load-mid span deflection curve for the SFRC PTL segment can be categorized into only two phases (Figure 1): ascending and descending parts. In the first phase, up to initial crack load (71 kN), a linear constant behavior was found. This initial crack load (71 kN) was approximately twice to that of the RC segment.

After development of sufficient cracks, the stresses in the segment's cross section increased leading to peak load (119 kN). Subsequently, the descending part of the curve began. The slope of the descending part changes as fibers were pulled out or fractured from the concrete matrix. This descending part of the SFRC PTL segment described more stable cracking behavior after peak load carrying capacity in comparison with the RC segment.

Flexural results showed that the initial cracking load for the SFRC segment was about 58 per cent higher in comparison with the RC segment. Furthermore, the SFRC segment demonstrated around 11 per cent lower cracking deflection than that of the RC segment due to enhanced anchorage and the crack bridging effect of steel fibers.

In the case of the SFRC segment, the crack width near to failure was noticed to be less than the limiting value (i.e., 0.3 mm) for serviceability conditions (Caratelli et al. 2011). This demonstrated the enhanced initial and failure cracking behavior of SFRC segment. This improved cracking behavior does not allow the penetration of harmful species inside the concrete leading to an enhanced mechanical and durability properties of SFRC PTL segments.

It was noticed that the peak load carrying capacity for the RC segment was significantly higher than that of the the SFRC segment, but, some necessary issues need to be recognized for designing PTL segments.

Firstly, the initial cracking load should be the main criteria for PTL segments during the fabrication processes in precast plants; segments are more likely subjected to accidental thrust and impact loads, which may result in segment cracking and therefore the structural integrity of segments could get disturbed (Moccihino et al. 2010).

Secondly, the serviceability condition for crack control needs to be satisfied. Both of these criteria favored the application of SFRC in tunnelling technology. Moreover, the above tested prototype SFRC segment was for initial investigation; the proper optimization of SFRC materials can minimize the peak load difference (Rivaz, 2008).

Durability performance

Chloride profiles

Figure 2 shows the chloride content in terms of percentage weight of concrete versus penetration depth. A declined pattern of chloride content was observed along with penetration depth for both the RC (normal concrete) and the SFRC specimens. The lower portions of chloride profiles were flat and assumed to reach the initial or baseline chloride content.

A similar chloride profile trend was observed for exposed and internal specimens for both concrete types. However, internal surface specimens showed higher ingress of chloride than that of exposed surface specimens for both normal concrete and SFRC (Figure 2).

This indicates that the internal surface specimen was more porous than the exposed surface. This may have resulted because of the application of cement slurry at the faces of the PTL segments, which closed the pores at the surface. At about 25mm from the ponding surface, the chloride content reached the baseline and showed no signs of penetration. This is in correlation with previous studies (Mangat and Gurusamy, 1987; Costa and Appleton, 1999; Roque et al. 2009).

The SFRC segment showed enhanced durability parameters compared with normal concrete due to lesser penetration of chlorides along the depth (Roque et al. 2009). This was due to the addition of steel fibers, which provide a barrier for the penetration of chlorides inside the concrete. After two weeks of salt ponding, the corrosion spots were observed at the surface of SFRC specimens.

These spots indicated the formation of corrosion materials, which further penetrated the small surface pores and restricted the ingress of Cl- ions (Balouch et al. 2010). Furthermore, SFRC specimens were further sliced in order to visually inspect the penetration of corrosion. No clear signs of corrosion on embedded steel fibers were noticed after 5mm from the ponding surface.

Table 2. Diffusion coefficient and surface chlorides

Concrete type	Surface	Diffusion ($x10^{-12}$ m^2/sec)
Normal concrete	Exposed	4.06
	Internal	4.89
SFRC	Exposed	2.39
	Internal	3.22

Source: Authors

Diffusion coefficient

Chloride ingress inside the concrete was measured as a diffusion process (Bamforth and Chapman-Andrews, 1994; Polder and Larbi, 1995). Fick's second law (Equation 1) was used to investigate the chloride diffusion inside the concrete for a non-steady situation (Crank, 1975).

Where C is the concentration of chloride ion; t represents the time; D is the diffusion coefficient and is a position variable. This solution of Equation 1 can be determined by applying the following boundary conditions (Crank, 1975):

Equation 1

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 C}{\partial^2 x}$$

- The concentration at the surface remains constant
- Initially concentration is zero in the concrete, and
- The concentration is zero at a very far distance from the surface.

Substituting these boundary conditions in Equation 1 resulted as follows,

Equation 2

$$C(x,t) = C\left[1 - \text{erf}\left(\frac{x}{\sqrt{4Dt}}\right)\right]$$

Where, erf is the error function. The potential chloride profiles were fitted using Equation 2 in order to determine the diffusion coefficient (D). The

Table 3. RCPT results for normal concrete and SFRC

Concrete type	Surface	Average (Coulombs)	Standard deviation	Coefficient of variation
Normal concrete	46	46	46	46
	38	38	38	38
SFRC	33	33	33	33
	33	33	33	33

Source: Authors

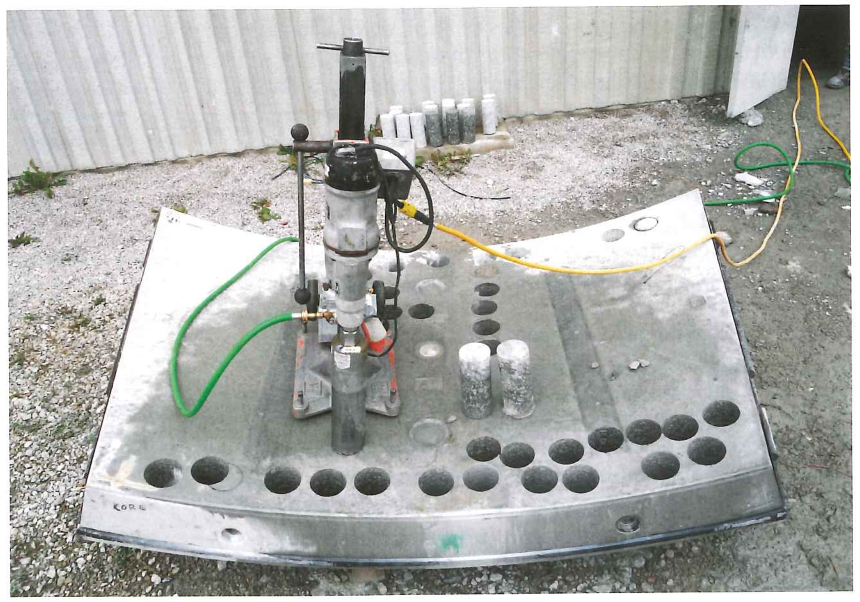
regression analysis of equation 2 showed the description of chloride diffusion into the concrete as the determination coefficient (R2) varied between 0.91 and 0.99 (Costa and Appleton, 1999).

Table 2 shows the diffusion coefficient results for normal concrete and SFRC using RC and SFRC segments. Results showed that exposed surfaces exhibited 17 per cent and 26 per cent lower diffusion coefficients than that of internal surface for normal concrete and SFRC, respectively. This indicated that the exposed surfaces are less porous than that of internal surfaces as explained previously.

It was found that SFRC exhibited 41 per cent and 34 per cent lower diffusion coefficients than that of normal concrete for exposed and internal surfaces, respectively. The lower diffusion rate in SFRC was the consequence of steel fibers, which provided a barrier for the chloride penetration inside the concrete.

Electrical resistivity of chloride ion penetration

Table 3 shows the average results of five concrete specimens. The coefficient of variation ranged from 6 per cent to 9 per cent for all the specimens, which satisfied the ASTM C1202 limit (i.e., 12.3 per cent). These results of normal concrete and SFRC were in correlation with other studies (Gergely et al. 2006; Vaishali and Rao, 2012).



***Above:** The coring process and cores*

***Below:** Core samples with corrosion spots*

The exposed surfaces showed 12 per cent and 8 per cent lower coulombs values than that of the internal surfaces for normal concrete and SFRC, respectively. SFRC specimens showed 23 per cent lower coulombs values than that of normal concrete for exposed surfaces. This difference was higher for internal surfaces (i.e., 27 per cent lower than that of normal concrete). This enhanced performance of SFRC was due to the contribution of steel fibers, which does not allow plastic and drying shrinkage cracks, which restricted the formation of small pores. This resulted in decreased penetrability properties (Vaishali and Rao, 2012).

CONCLUSIONS

In this study structural and durability aspects of RC and SFRC PTL segments were investigated. The following are the conclusions drawn from this study.

1. The SFRC PTL segment showed more stable initial and failure cracking behavior compared with the RC segment. Moreover, SFRC exhibited a higher cracking load than that of the RC segment. The exact optimization of SFRC materials is the key for its successful applications in tunnelling technology.
2. The exposed finished surfaces of RC and SFRC PTL segments exhibited better durability properties than that of the internal surfaces.
3. SFRC cored specimens showed less penetration of chloride than that of normal concrete specimens. Moreover, SFRC exhibited a lower chloride diffusion coefficient compared with normal concrete.
4. SFRC cored samples exhibited lower coulombs values than that of RC specimens

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Participants on a tunnelling field course

A BROAD EDUCATION

Implementing sustainable field training for geology and geological engineering is mutually beneficial for students and industry. **Nicholas Vlachopoulos**, professor in the civil engineering department, and **Efrosyni-Maria Skordaki**, geosciences research staff, both of the *Royal Military College of Canada*, report on a tunnelling field course in Greece

AS WITH ANY GRADUATE program within the realm of geological and geotechnical engineering, there is a unique requirement to conduct field exercises to expose the students to the geology, real-life projects, experiences and working conditions with a view to reinforcing concepts that have been introduced in the traditional university classroom environment. Not only do the students benefit from such hands-on experiences, but the construction companies and contractors also benefit by positively influencing the students through the showcasing of their profession.

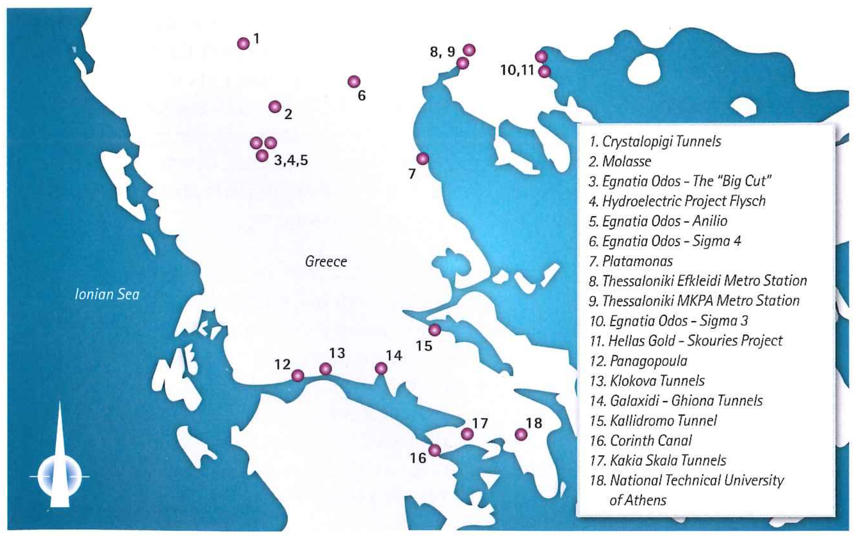
To this end, an international field course involving four universities was conducted from Monday, December 7 to Sunday, December 13, 2015. This graduate course is run annually by Paul Marinos (past-president, International Association of Engineering Geologists [IAEG]) at the National Technical University of Athens (NTUA). This year, as in previous years, the course was planned, organised and conducted in collaboration with the Civil Engineering Department at the Royal Military College of Canada (RMC), the Geological Sciences and Geological Engineering Department at Queen's University, NTUA and the Aristotle University of Thessaloniki (AUTH). An active, Canada-Greece inter-university collaboration in this regard has been established between these universities spanning more than 12 years. Organisers and instructors for the Canadian Universities were Nicholas Vlachopoulos, RMC/Queen's, and Mark Diederichs, Queen's University. Eight graduate students from RMC-Queen's Canada participated in the course. This 'Canadian Contingent' was accompanied by eight graduate students from the graduate program of the Geology Department at AUTH, and 21 graduate students from the graduate program of the Schools of Mining and Metallurgical Engineering and Civil Engineering from the NTUA. Vassilios Marinos, assistant professor at AUTH also contributed with his expertise during the course.

The course involved circumnavigating Greece and visiting tunnelling sites (primarily road, rail, and mines) throughout the country. Greece is a country born of intense tectonic processes; being at the boundary of the African and Eurasian tectonic plates. Highly-deformed and altered sediments and low grade metamorphic rock masses dominate the near surface environment creating a variety of technical challenges for tunnelling and slope stability related to modern infrastructure. The students certainly witnessed these issues first-hand. The underground construction works were conducted in limestones, clays, gneiss, molassic rocks, flysch, phyllites, ophiolites, basement schists and fault zones. The tunnels were at various stages of construction and the graduate-student work along the way included geological model construction, seismic hazard prediction, ground classification and tunnel design with student presentations in the evenings among other deliverables.

There are certainly many active or recently completed tunnelling sites in Greece at the moment. Sites on this course included: Kakia Skala Road and Rail Tunnels; the Corinth Canal; Panagopoula Road Tunnel of Corinth-Patras Highway; Klokova Tunnel of the Ionian Highway; Gkiona Hydraulic Tunnel of Mornos-Athens; Kallidromo Rail Tunnel; Platamonas Tempi Road Tunnel; Thessaloniki Subway Tunnel, Euclid Station and Kalamaria Extension and TBMs; Hellas Gold Mine sites in Chalkidiki, Skoureies and Olympiada; Tunnels of Egnatia Odos; multiple tunnels (20+), Sigma3, Anilio, Metsovo, Anthochori tunnels; as well as the 'Great Cut' embankment; Crystallopigi Tunnels; multiple outcrops and rockmass characterization; Achellos diversion project by DEH (dams and power houses, tunnels); and Meteora Conglomerate formations.

Throughout the course, the graduate students were able to see the various challenges when tunnelling through materials with varying strengths and properties and in regions with inherent landslide as well as seismic risks. Of note, was the fact that the students had the unique chance to visit the Olympia and Skouries mine sites in Chalkidiki. The mines are rich in copper, gold, silver, and zinc in both surface and subsurface deposits. Greece has not played a significant role in the mining of such commodities for decades and as such, there are many unique challenges associated with the development of this site on a technical, social, and environmental level. It was an excellent opportunity for the student to witness how design and construction practices in mining differ from conventional highway or rail tunnels as well as the significant focus on worker safety and the environment.

Above: **Paul Marinos with Canadian students**



Below: **Map of Hellas depicting selected sites that were visited during the field course**

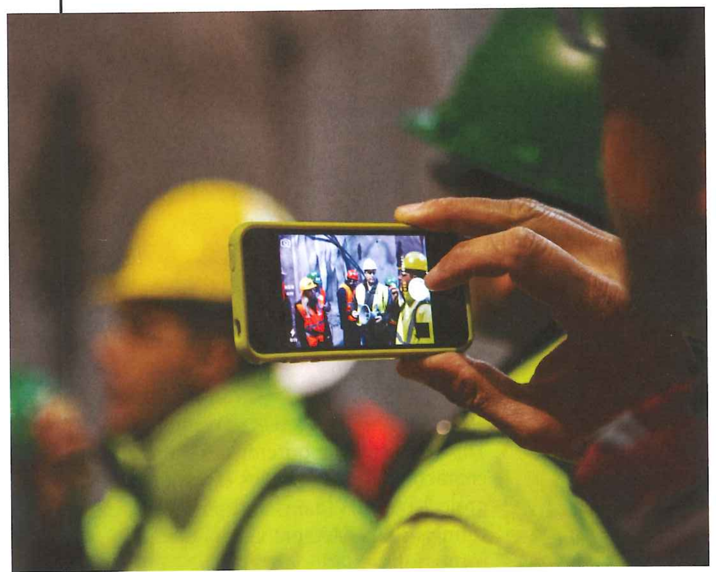
Nicholas Vlachopoulos
Nicholas is a professor with the Royal Military College of Canada

Efrosyni-Maria Skordaki
Efrosyni-Maria is geosciences research staff with the Royal Military College of Canada

Table 1. Blended learning component of field exercise (description of requirements).

Pre-field exercise self-assessment -selected questions	Online journals	Critical reviews (critiques) of posted daily reflections	Post-field exercise self-assessment
How do you anticipate this field trip to support your learning in geoengineering? Include specific areas of learning that you would like to expand on (such as field work practices, identification of particular geological formations, field data collection, etc.).	Describe the following: For each day of the technical tour, what were the most important technical characteristics of the sites that you visited? Describe and critically reflect on the information that was presented onsite by course instructors, consulting engineers, technical company representatives, etc. Was the information that was provided helpful to you? Why, or why not? What new did you learn? What specific areas/topics would you like to know more about?	For each critique, critically examine the content of a daily reflection post of your choice. Are there any key technical characteristics about the information on the sites that are missing in the post you are evaluating? Are there any features about a particular site that you would like to highlight or elaborate upon? Feel free to share any new information such as a web site link or bibliography that is relevant to the information presented in the post.	Did the field exercise meet your learning needs as a geoengineering graduate student? Did you gain new knowledge in the technical areas that you were hoping to expand on? Why or why not? During this technical tour, did you visit any sites that attracted your research interest in particular? If yes, which ones? Why? Please explain.

Source: Authors



***Above:* Cellular phones were among the technologies used to capture and record all aspects of the field components**

A major contributor to the feasibility and success of such field courses is the buy-in and significant financial support provided by the tunnelling companies and contractors. Without such support and access to the underground works, these sorts of ventures would not be practicable. The companies see the need to help educate and expose the next generation of geological engineers or geoscientists to such sites. The direct access by the students to site engineers, workers and employees at all levels adds much value to the overall experience and compliment fully the objectives of the course.

The authors' experience in Canada has been that access to underground works of this nature are quite limited due (primarily) to liability considerations. The authors would welcome the opportunity to conduct such field courses in Canada in cooperation with tunnelling companies that would involve multiple and a diverse array of sites.

FRAMEWORK FOR SUSTAINABLE FIELD COURSE DESIGN

The field course was reviewed with current higher education research in mind and complemented with blended learning components (i.e., on-site instruction combined with on-line communication and critique of retained information) in order to enhance the instructional environment and provide a record of the field course's activities and lessons learned for future courses. What makes fieldwork so valuable to learning geoscience?

Pyle (2009) identifies the main goals of field courses as a) synthesis and application of knowledge; b) acquiring the field skills and techniques typically required for an entry-level, professional geologist; c) enculturation into the values and ethics of practicing geoscience; and d) exposing students to the variety of geologic phenomena they may encounter. Similarly, Mogk and Goodwin (2012) review arguments based on "practitioner's wisdom" claiming that field education yields improvements in students' knowledge and problem-solving skills, enhances students' ability to reflect on their own thinking (metacognition), generates positive feelings that lead to enhanced learning, offers direct and immersive experiences of geologic phenomena, and introduces students to professional practice" (Petcovic, Stokes & Caulkins, 2014).

Specifically, blended learning components of the field course involved: a) a pre-field exercise self-assessment, b) daily online journals posted on the course's website by the students tied to the information that was presented each day of the field exercise, c) critiques of online journals among peers, and d) a post-field exercise self-assessment (Table 1).

Much academic debate has been dedicated to determining the necessary balance of methods and tools to be included in a geological sciences and geoengineering program. Consideration of several factors is warranted, the most prevalent of these factors being the current state of industry and their requirements, technological advancements, sustainability education as well as instructional methods informed by ongoing education research. The re-design of the course to include the use of blended (onsite/online) learning as well as synchronous/asynchronous interactions was conducted with a view to enhancing the learning outcomes of the geological and geotechnical field exercises.

By using existing technology and pedagogy in field training, we sought to: a) Identify the diverse learning needs of the students and connect them to the learning outcomes of the field course, b) investigate the value of the field exercise specifically for each student with a view to informing the design of future field exercises with a learner-centred approach, and c) allow for the production of student-generated teaching material (discussion forum posts, student reflections, videos, photos) that would capture the field exercise activities through the eyes of the learners.

The results of the pilot study were in agreement with other researchers in the sustainable education realm in the sense that geological field training may also be in need of "a redesigned educational paradigm that is in essence relational, engaged, ethically oriented, and locally and globally relevant." (Stirling, 2001).

By combining: a) specialised technical information provided by experts in the field, b) assignments promoting student reflection on their actual learning during their participation in technical tours and onsite field exercises, and d) synchronous/asynchronous peer collaboration and online critiquing and archiving of information, the authors set the framework for sustainable field training in geosciences/geoengineering.

Not only was this field course a memorable one from a technical perspective, but it was also an experience that the students will remember as a cultural exchange.

For the duration of the visit, the generosity as well as warm culture of the Greek people was a highlight, as at no moment was there a lack of hospitality or kindness.

A common takeaway was about embracing culture of the Greeks who have a passion for learning, teaching, and expanding their knowledge base. This was highlighted by the fact that due to the enthusiasm of Greek GeoProfessionals (in particular, Hydro Greece staff that travelled more than 200km to provide students access to an underground power generation cavern).

In this respect, there was no evidence of any crisis in Greece. The Canadian Contingent enjoyed learning about the Greek culture, and feasting in their delicious and varied cuisine. This field course helped all those that were privileged to take part in it to grow personally and take a little bit of Greece back to Canada with them; as Paul Marinos himself put it, "You are now all Greek!"

This type of international collaboration between these institutions that has spanned more than a decade has won high praise from the Embassy of Canada to the Hellenic Republic, specifically, from ambassador Keith Morrill himself. We look forward to future venues and collaborations with a view to improving such experiences for our graduate students – in a sustainable fashion

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***Below:* Queen's University graduate student Natalie Blacklock enjoys the last day of the field course overlooking the conglomerate formations at Meteora, Kalampaka**

EFFICIENT DESIGN OF OPENINGS IN SCL TUNNELS

This paper by **Dr. Angelos Gakis** and **Petr Salak,** both senior tunnel engineers and design managers for *Dr. Sauer & Partners*, presents the case for SFRC being sufficient to support an SCL tunnel opening, without the need for additional reinforcement

OPENINGS IN THE LINING of sprayed concrete lined (SCL) structures are common in mined stations where two or more tunnels intersect. The formation of an opening in a SCL structure results in redistribution of stresses in the concrete shell around it. The use of steel fibre reinforced (SFR) sprayed concrete, may prove adequate to reduce or eliminate the need for strengthening of the parent tunnel around the opening.

Considering a typical junction between two SCL tunnels, the main factors affecting the post-opening stress distribution as well as a proposed design approach are discussed in this article. The presented design philosophy, delivered significant health and safety, time, resource and environmental benefits by enabling a large number of openings to be successfully built without introducing any steel mesh/bar reinforcement or additional lining thickenings.

COMMON PRACTICE

Introducing openings in SCL tunnels results in high compressive hoop forces at the sides of the opening and increased tensile forces (both hoop and longitudinal) and bending moments above and below.

The purpose of the design is to predict the final stress state in order to assess whether additional support is required. Basic design approaches include analytical/empirical solutions or two-dimensional (2D) numerical analyses. These design approaches however have limitations as they ignore the out-of-plane bending moments, the soil-structure interaction and the construction sequence, while assuming a linear elastic model for the SCL.

As a result, excessive stress changes are calculated around the opening, translated into reinforcement required to accommodate the tension/flexure and thickening of the SCL to install this reinforcement and resist possible compressive overstressing.

A thorough literature review of the available methods can be found in [8]. Three-dimensional (3D) numerical analyses, simulating the soil structure interaction and the construction sequence, overcome most of the aforementioned limitations.

It will be illustrated however, that even a full 3D Finite Element (FE) analysis may result in conservative designs if the plastic parameters of the SCL (in particular the post-crack residual tensile flexural strength) are ignored.

DESIGN APPROACH FOR STEEL FIBRE REINFORCED SCL

Steel fibres are mainly used with SCL to enhance the durability and ductility of the linings. Most of the tunnel design FE codes however, provide the option to model the SCL only as a linear elastic material. As a result, high tensile forces and bending moments are calculated around the opening, rendering necessary the use of reinforcement to accommodate the excessive tension/flexure.

The elastic-plastic "concrete damaged plasticity model" in FE code Abaqus (Dassault Systemes Simulia [3]), provides the option to simulate the SFR SCL as ideally elastic prior to compressive and tensile yield. The compressive strength and residual tensile strength parameters are considered in the post-yield states.

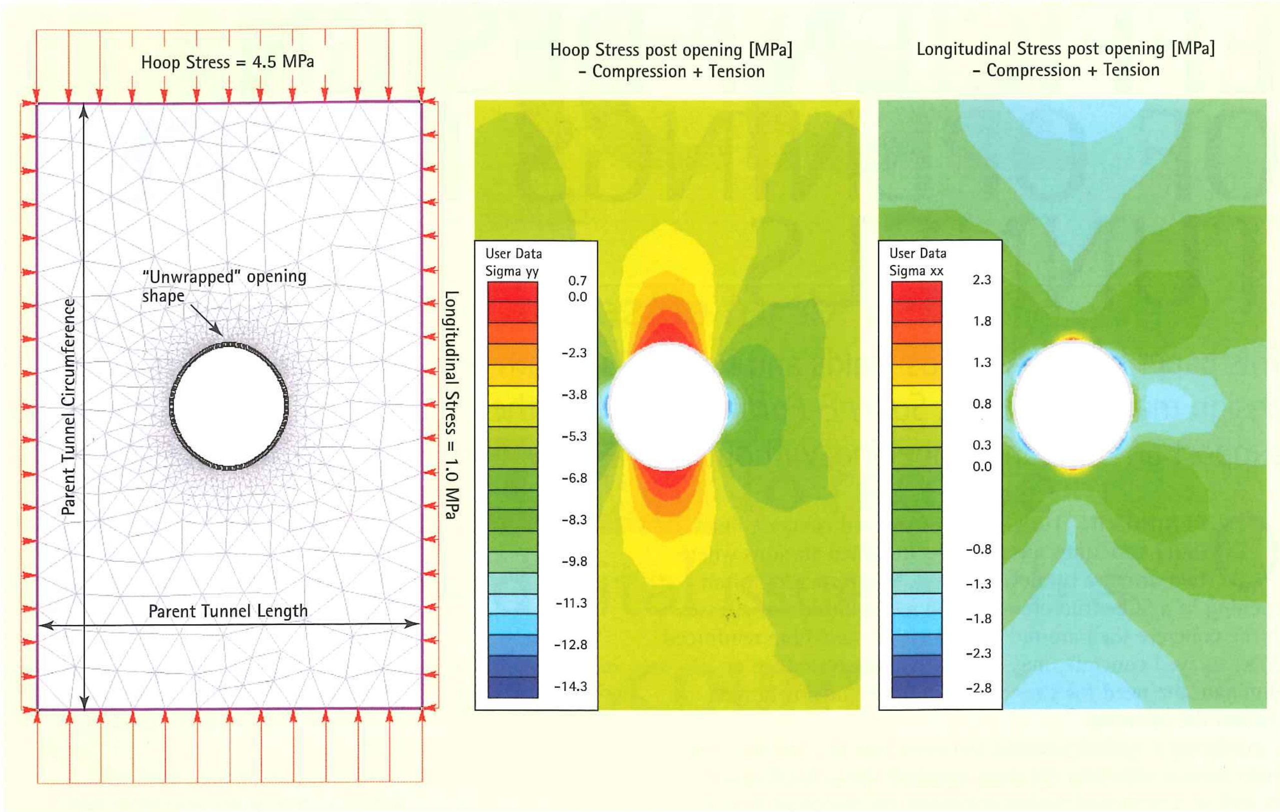
Furthermore, using the recommendations provided in [4] and [6] in line with the Eurocodes ([1], [2]) the capacity of the SFRC lining for sections under axial load and bending is checked using capacity limit curves [7] and through inspection output strains in the FE models.

PARAMETRIC STUDY

In order to compare the results of different design approaches, a parametric study

Dr. Angelos Gakis
Angelos was the winner of the 2015 Crossrail technical paper competition

Petr Salak
Petr founded Think Deep UK, an advocate for the sustainable use of underground space



was undertaken utilising the following three types of analysis:

- 2D FE plane stress analysis (2D),
- Full 3D FE analysis with ideal elastic SCL (elastic 3D),
- Full 3D FE analysis using the concrete damaged plasticity model for the SCL (plastic 3D), where the tensile strength of the SCL was set at 300kPa and the compressive strength at 28MPa.

***Above:* Figure 1, 2D FE plane stress analysis results of a typical junction (Circular Parent tunnel – Ar=60%)**

The parent tunnel was steel fibre reinforced SCL, 400mm thick with its axis at 25m below ground level. Three cross sections with almost equal cross sectional area and perimeter were examined:

i. "Circle" 10m diameter,
ii. "Horizontal" ellipse (H-Ellipse) 8.9m vertical diameter and 11.2m horizontal and
iii. "Vertical" ellipse (V-Ellipse) 11.2m vertical diameter and 8.9m horizontal.

Additionally, three different values were considered for the height aspect ratio (Ar=Circular Child tunnel height/ Parent tunnel height): 60%, 70% and 80%.

For simplicity, the soil in the 3D FE analyses was modelled as an isotropic, linear elastic material (Young's modulus = 100MPa).

In the 2D plane stress analysis the parent tunnel geometry including the opening is being "unfolded" and flattened into a 2D surface and the developed shape is introduced in the FE model (see Figure 1). The pre-opening hoop and longitudinal stresses in the parent tunnel are assigned at the boundaries of the mesh.

For the sake of comparison these stresses have been taken from the 3D FE models although it is possible to use approximations given by empirical relationships or simplified 2D FE analyses. Figure 1 shows the resulted stress changes for the base case of a circular tunnel with Ar =60%, using the FE code Phase 2 (Rocscience).

The 3D FE analyses have been carried out using Abaqus. The results for the same example have been plotted in Figure 2.

RESULTS OF PARAMETRIC STUDY

The complete results of the parametric study are shown in the graphs of Figure 3. The most important conclusions are the following:

- Hoop compressive stress changes at the sides of the opening were underestimated in most of the 2D analyses. Both 3D analyses results are similar. The shape and the aspect ratio did not affect the maximum values notably.
- Hoop tensile stress changes above and below the opening were overestimated in 2D. The plastic 3D analyses predicted slightly higher values than the elastic results.
- The longitudinal stress changes above and below the opening were considerably affected by the method of analysis. The 2D predicted significant tension, with lower values predicted by the elastic 3D. In the plastic 3D however, the stress changes were very small.
- Higher bending moments above and below the opening were predicted in the elastic 3D compared to the plastic 3D analyses.
- The effects of the shape and the aspect ratio did not follow a specific pattern. The aspect ratio affected mainly the stresses above and below the opening in the horizontal ellipse. Furthermore, both 3D analyses predicted slightly higher compressive stresses at the sides of the opening in the horizontal ellipse.

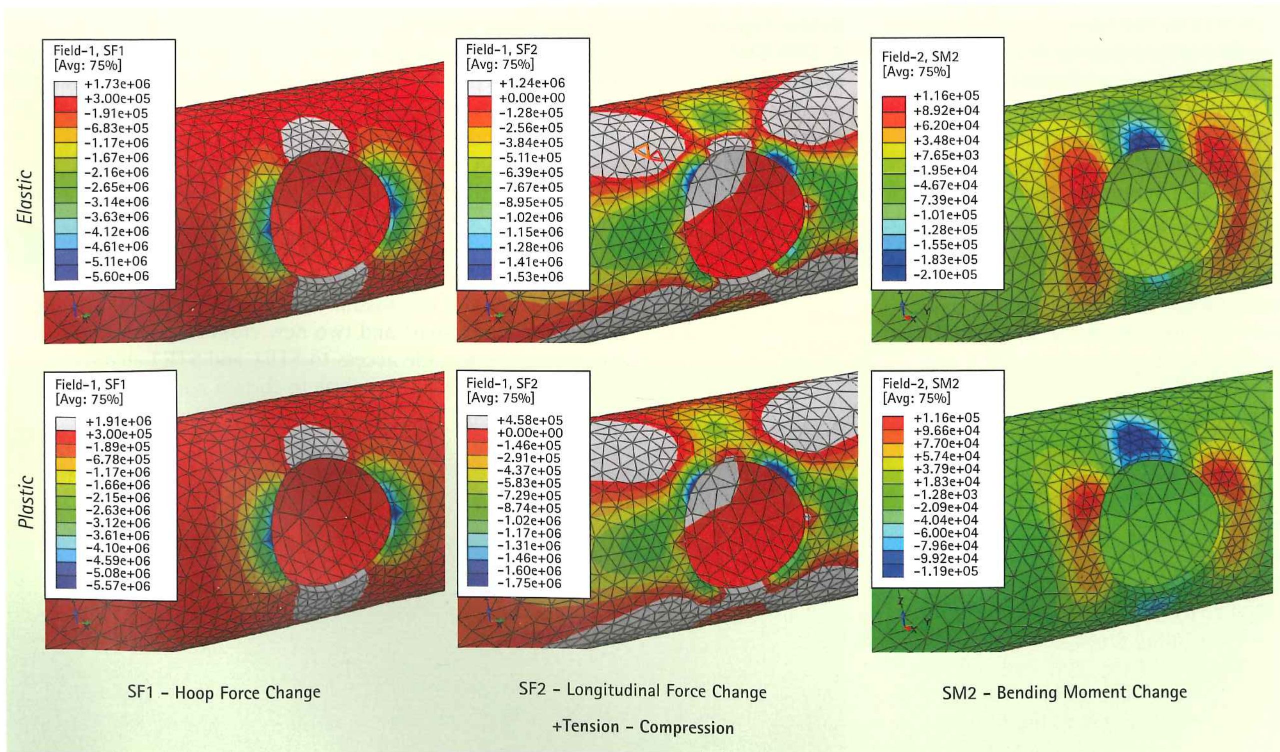

Photo of early SCL works at Farringdon from the Tunnels and Tunnelling archive

***Above:* Panorama of (left to right) CP1, CP1-CH1 connection adit and PL2RC. Described on p.48**

***Below:* Figure 2, Full 3D FE analysis results of a typical junction (Circular Parent tunnel - Ar=60%) for a linear elastic and plastic SCL. A zero cut-off has been applied on SF1, SF2 to highlight areas of positive (tensile) stress changes**

The following limitations of this study should be noted:

- The conclusions are based on specific tunnel size and depth and ground properties. In order to draw more broadly applicable conclusions, the size and depth of the tunnel as well as the ground stiffness and the k_0 will have to be varied.
- Only openings in the primary lining of SCL tunnels were considered. The effect of the openings in final linings depend on the design principles (type of lining, design loads, waterproofing).
- Openings in SCL shafts have not been assessed. Similar principles may apply there, however the initial and resulting stress states are different than in the SCL tunnels.
- The effect of the excavation of the child tunnel and the stiffness of its



connection to the parent tunnel have not been considered in this study.

CASE STUDIES

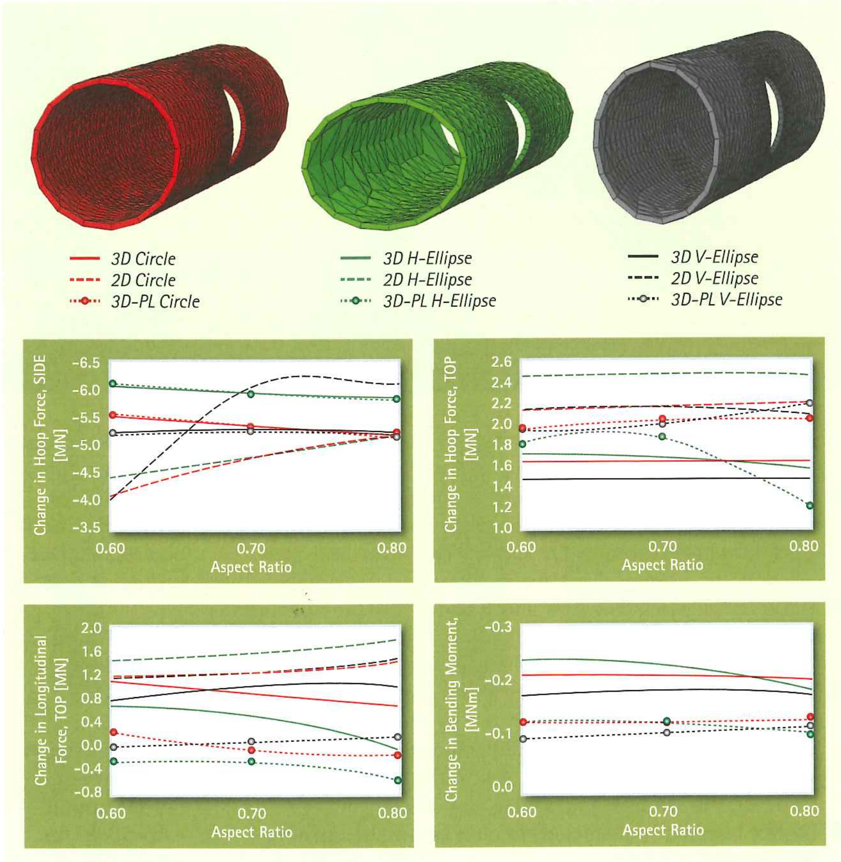
The proposed design approach for openings in SFR SCL presented above was applied successfully in multiple instances. Two examples from Crossrail Farringdon Station are presented. Farringdon station comprises two ticket halls, two escalator/concourse tunnels, two platform tunnels, numerous cross passages and ventilation tunnels as well as four stub tunnels, all built using SCL techniques. As the tunnels were constructed 85% in the Lambeth Group, Farringdon provided a unique insight in this challenging formation. The generally stiff-very stiff overconsolidated clays of the Lambeth Group included interbedded water bearing sand lenses, of random distribution. These, approximately 3m thick lenses, combined with the five geological faults that crossed the station imposed considerable risks on the SCL works.

BAM Ferrovial Kier (BFK) joint venture, the main contractor, appointed Dr. Sauer & Partners as specialist SCL designer. The design team was co-located within the BFK offices to provide rapid and effective design support. Key Dr. Sauer & Partners employees were also embedded into the BFK Engineering team to provide a degree of independence and assurance within the Contractor's delivery team. An opportunity was identified by the team to improve the baseline programme by designing and constructing five additional temporary SCL structures to provide vital logistics supply routes to support tunnelling operations.

All five temporary structures included openings and were successfully designed and constructed without additional steel bar reinforcement and/or additional thickenings [5]. Two of these examples were the opening in cross passage CP1 and in reception chambers STE1 and STE2.

CP1 OPENING

A temporary SCL connection adit (CP1-CH1) was designed and constructed between cross passage CP1 and concourse tunnel CH1, allowing CH1 to be built in advance of escalator barrel ES1 (see Figure 4), thus providing significant programme savings. The construction of the temporary adit was particularly difficult as CP1, constrained by its close proximity to the future escalator barrel ES1, had a cross section



Above: ***Figure 3, Results of the parametric study (forces in MN, moments in MNm)***

Below: ***Figure 4, CP1-CH1 longitudinal section (left) and cross section (right)***

prescribed by the permanent works design.

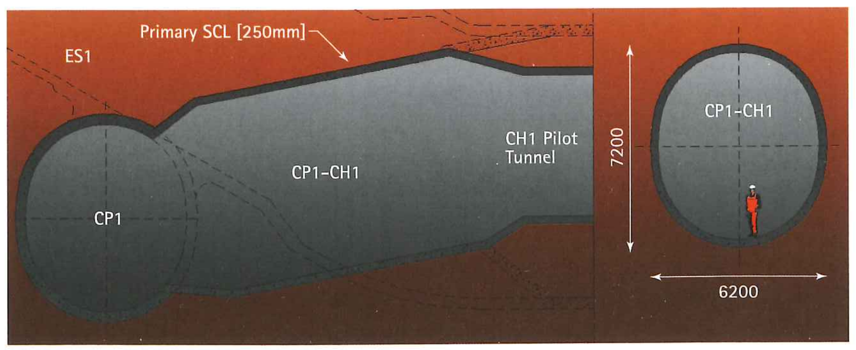
This limiting factor resulted in an optimised breakout from CP1 towards CH1, which flared out from the breakout to allow more space for the tunnelling operations but still posed considerable logistic challenges.

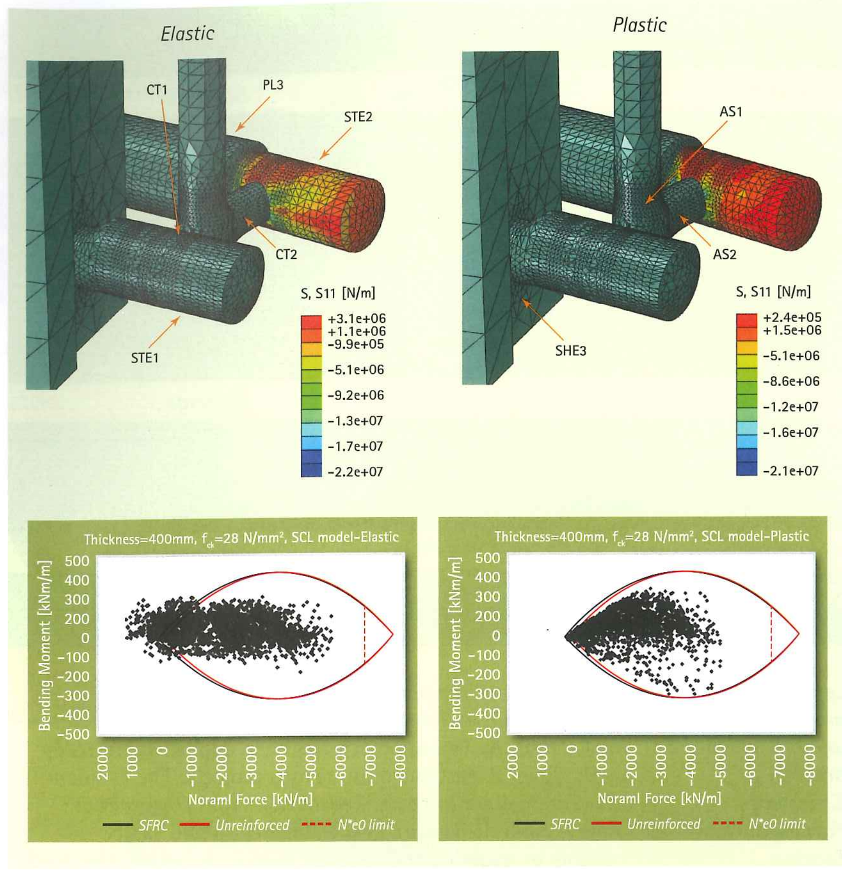
CP1 is 7,200mm high and 6,200mm wide with a 250mm thick SFR SCL and the required opening in the CP1 was 5,385mm high resulting in an aspect ratio of 75%. The contractor had a strong preference to explicitly use SFR linings throughout to provide health and safety benefits, maximising the amount of mechanisation, reducing manual handling, eliminating working at height and steel fixing.

The opening was assessed following the proposed design approach and the results allowed the sole use of SCL without any additional reinforcement.

STE1 AND STE2 OPENINGS

At the eastern end of Crossrail Farringdon station, a temporary access shaft and two new cross tunnels were constructed to provide access to STE1 and STE2 chambers (see Figure 5). The purpose was to form a connection





between the surface and the running tunnels for future first stage concrete and track slab works between Farringdon and Liverpool Street Station.

The temporary access shaft was constructed using precast concrete rings and sprayed concrete lining (SCL) techniques (part AS1 and AS2). Subsequently, two connection SCL tunnels (CT1 and CT2) were constructed and connected to STE1 and STE2. The TBM reception chambers STE1 and STE2 are 9,010mm high and 9,410mm wide with 400mm thick SFRC linings. The openings for CT1 and CT2 tunnels are 5,020mm high and 5,000mm wide with an aspect ratio of 55%. The openings were formed without any additional strengthening of the tunnel lining.

Demonstrating the main conclusions of the parametric study, two design models are compared in Figure 5: the elastic 3D FE model and the calculated hoop stresses with the corresponding capacity limit curve for STE2 is shown on the left and the plastic 3D FE model is shown on the right.

Implementing the residual tensile strength of the SFR SCL in the analysis has reduced the tension with a slight increase in the bending moments, without however any exceedance of the lining capacity.

Above: ***Figure 5, Calculated hoop stresses and capacity limit curves for elastic (left) and plastic (right) SCL of TBM reception chamber STE2***

BENEFITS

The proposed design method when applied in tunnels and shafts brings important benefits. These benefits have been identified in Table 1 for three distinct categories: Health & Safety, construction (including time & cost savings and quality improvement) and environmental benefits.

To further quantify the benefits arising from openings without additional layers of SCL thickening and without steel bar and/or mesh reinforcement, a typical junction between a 10m diameter parent tunnel, 400mm thick and an 8m diameter child tunnel (Ar=80%) was considered. The savings in programme duration, material usage and CO_2 emissions resulting from the avoidance of installing reinforcement and SCL thickening around the openings were assessed and are presented in Table 2 (next page).

CONCLUSIONS

Advanced design tools combined with the improved knowledge of material behaviour provide opportunities for improved designs. Every case however should be examined individually. The proposed design philosophy exploits the capabilities of non-linear 3D

Table 1. Benefits arising from the avoidance of additional strengthening measures prior to the opening

	Health & Safety Benefits	Construction Benefits (time/cost/quality)	Environmental Benefits
Eliminating manual handling	•	•	
Faster execution		•	
Improved Spraying quality		•	
Maximum mechanisation	•	•	
No spraying on reinforcement	•		
No steel fixing	•	•	•
No works at height	•		
Smaller excavation volume		•	•
Smaller SCL volume		•	•

Source: Authors

Table 2. Savings in programme duration, material usage and environmental impact when avoiding the installation of additional reinforcement and SCL thickening in one opening

Programme duration	Savings
Excavation	1 day
Fixing of rebar in invert	1 day
Spraying invert up to axis and cleaning	1 day
Backfill and fixing of rebar in crown	1.5 days
Spraying crown	1 day
Cleaning and waiting for concrete strength	0.5 days
Sub total:	6 days
Material use	**Savings**
Steel bar and/or mesh reinforcement per opening	3-6 tonnes
Additional thickening - SFRC (assuming 400mm thick)	≈160m^3
Additional excavation	≈160m^3
Environmental impact	**Savings**
CO_2 emissions (assuming only 150kg/tonne of reinforced concrete)	≈50 tonnes

Source: Authors

Left: **Commencement of breakout using a hydraulic breaker at Crossrail's Farringdon Station**

Below: **Completed opening - excavation of "child" tunnel**

The authors would like to acknowledge the BFK JV and Crossrail

FE analysis and the plasticity characteristics of steel fibre reinforced SCL in order to optimise the design of openings in SCL tunnels. This approach has been applied successfully by Dr. Sauer & Partners in numerous projects. The avoidance of additional reinforcement permitted rapid construction progress and delivered considerable health and safety benefits by avoiding the need for manual handling, the need to work at height and steel fixing.

Extrapolating the savings discussed in Table 2 in a mined station with 20 openings for example, may result in savings of 120 days in programme duration, 90 tonnes of steel, 3,000m^3 of concrete, 3,000m^3 of excavated material and 1,000 tonnes of CO_2 emissions.

This solution supported the industry drive of maximising the use of robotic and remote construction methods. In-tunnel and surface measurements during and after construction showed excellent correlation with the predicted tunnel deformations, thus validating the design approach and assumptions

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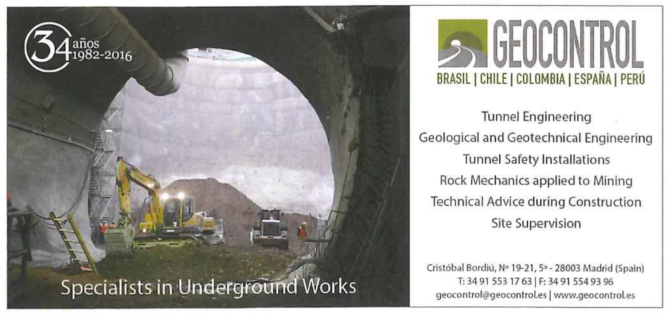

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www.expotunnel.it

TAC Conference
12-15 December 2016
Ottawa, Canada
The Tunnelling Association of Canada is pleased to welcome you to TAC 2016 Ottawa. The event will include technical sessions and an exhibition.
www.tac2016.ca

2nd Underground Solutions Seminar
9 November 2016
London, UK
This event, hosted at the Institution of Civil Engineers (ICE) in London has the following speakers confirmed: Colin Eddie (UnPS), Vincent van der Vrie (Trelleborg) and Paul Sparrow (Promat Tunnel). The organiser is Bekaert Maccaferri Underground Solutions.
www.bm-underground.com/uss

Underground Tunnel Technology Presentation
9 November 2016
London, UK
This presentation will be hosted at Mapei's Clerkenwell Specification Centre. For more information please contact Stephanie Brown at clerkenwell@mapei. co.uk
www.utt-mapei.com

ITA Tunnelling Awards
10-11 November 2016
Singapore
The ITA tunnelling awards 2016 is the second annual international competition to celebrate achievements in tunnelling and underground construction invites nominations. A two day Conference in Singapore is planned, including the Awards Conference and Banquet.
www.awards.ita-aites.org

Architex 2016
15-16 November 2016
Liverpool, UK
ArchitEx brings together architects, specifiers, building designers, developers, planning officers and suppliers together in a regional setting to explore local opportunities, debate topical issues, learn from national and international case studies, discuss the latest design trends, network with new contacts and to source the latest technology, products and materials. Split into eight sessions this is an ideal opportunity for attendees to gain ideas, ask questions and network.
www.architexevents.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 at home and abroad. This looks to be an impressive event following on from last year's which was hosted in Singapore.
www.tbmdigsturkey.org

Global Tunnels Safety and Fire Protection Summit
16-18 November 2016
Istanbul, Turkey
With tunnel development growing at such a fast rate worldwide, fire protection and safety measures have come to the forefront on everyone's mind. Safety and the technologies that go along with it will always be questioned to ensure that newly developed tunnels adhere to these best practices. Get a cross-industry view on big issues surrounding metro, roads and tunnels globally.
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Bauma China
22-25 November 2016
Shanghai, China
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www.bauma-china.com

Geotec Hanoi 2016
24-25 November 2016
Hanoi, Vietnam
Originated from October 2011, the first international conference Geotec Hanoi 2011 was excellently successful with about 450 attendees from 24 countries. Developed from the success of the two previous events, is organised by Fecon Corporation, the Vietnamese Society for Soil Mechanics and Geotechnical Engineering, and the Japanese Geotechnical Society (JGS)
www.geotechn.vn

Bauma Conexpo India
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2017

4th Arabian Tunnelling Conference
21-22 February 2017
Bergen, Norway
The ATC is the number one networking hub of Tunnelling and Underground Space experts and professionals in the region.
www.soeuae.ae

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

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

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
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.
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.
www.stuva-expo.com/en/

2018

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

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

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.

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

Over-tunnel construction at Amsterdam Station
20 October 2016
With great pressures on the use of urban overground space the need for construction directly around and over existing running tunnels has been increasing for decades. This presentation reveals the quay wall reconstruction at Amsterdam Central Station. The foundations of this quay wall intersect the north-south metro-line tunnel over a length of 600 ft. Rather than spanning the tunnel with heavy concrete slabs it "overhangs" the north-south subway line from two sides. Some piles pass at only 10 cm from the tunnel lining. The technical challenges of design and installation at such close proximity to the tunnels are discussed including the implications for taller structures.
Speaker: Robin Vervoorn, Witteveen+Bos UK

The Crossrail experience
17 November 2016
In May 2015, major tunnelling was completed on Europe's largest construction project with the arrival of TBM Victoria at Farringdon station under the heart of London. A total of 42km of tunnels were constructed using six earth pressure balance TBMs, two mixed-shield slurry TBMs, 250,000 pre-cast segments and over 3.5km of sprayed concrete lining to form ten platform tunnel sections at five stations. Work commenced in 2009 with design and TBM specifications, preparation of execution and procurement strategies, securing of land rights, installation of over 35,000 prisms to monitor ground and structure movement, and development of a strategy for disposing of seven million tonnes of excavated material, which included creation of a new bird sanctuary for the Royal Society for Protection of Birds in the Thames estuary. This paper will chronicle Crossrail's experience and provide important lessons learned for future projects that involve major tunnelling in a complex urban environment.
Speakers: Bill Tucker and Mike Black, Crossrail

BTS Christmas debate
20 October 2016
The annual BTS Christmas debate takes place this year on 8 December. Two sides meet to debate a topic apposite to tunnelling.
Speakers: 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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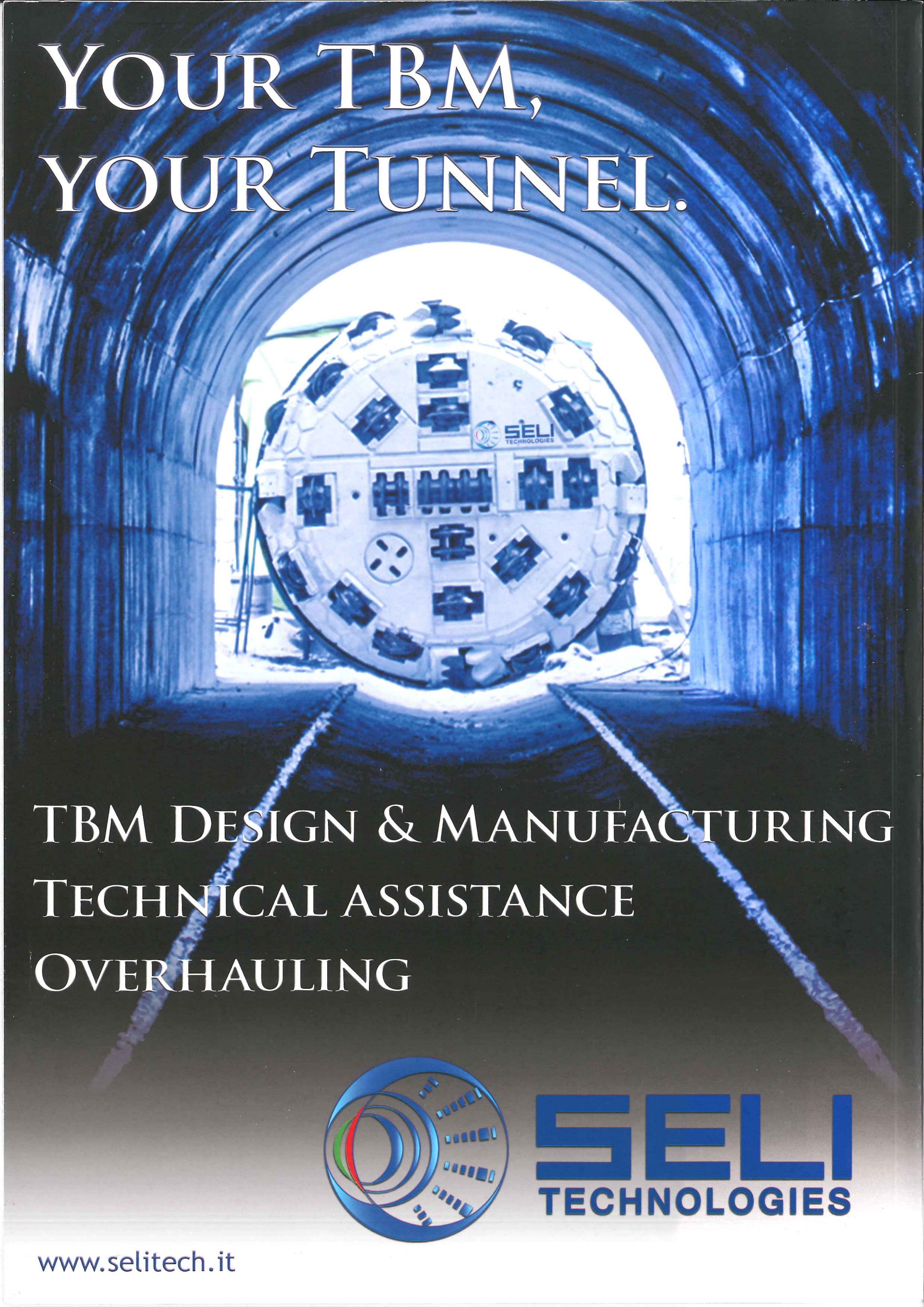
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