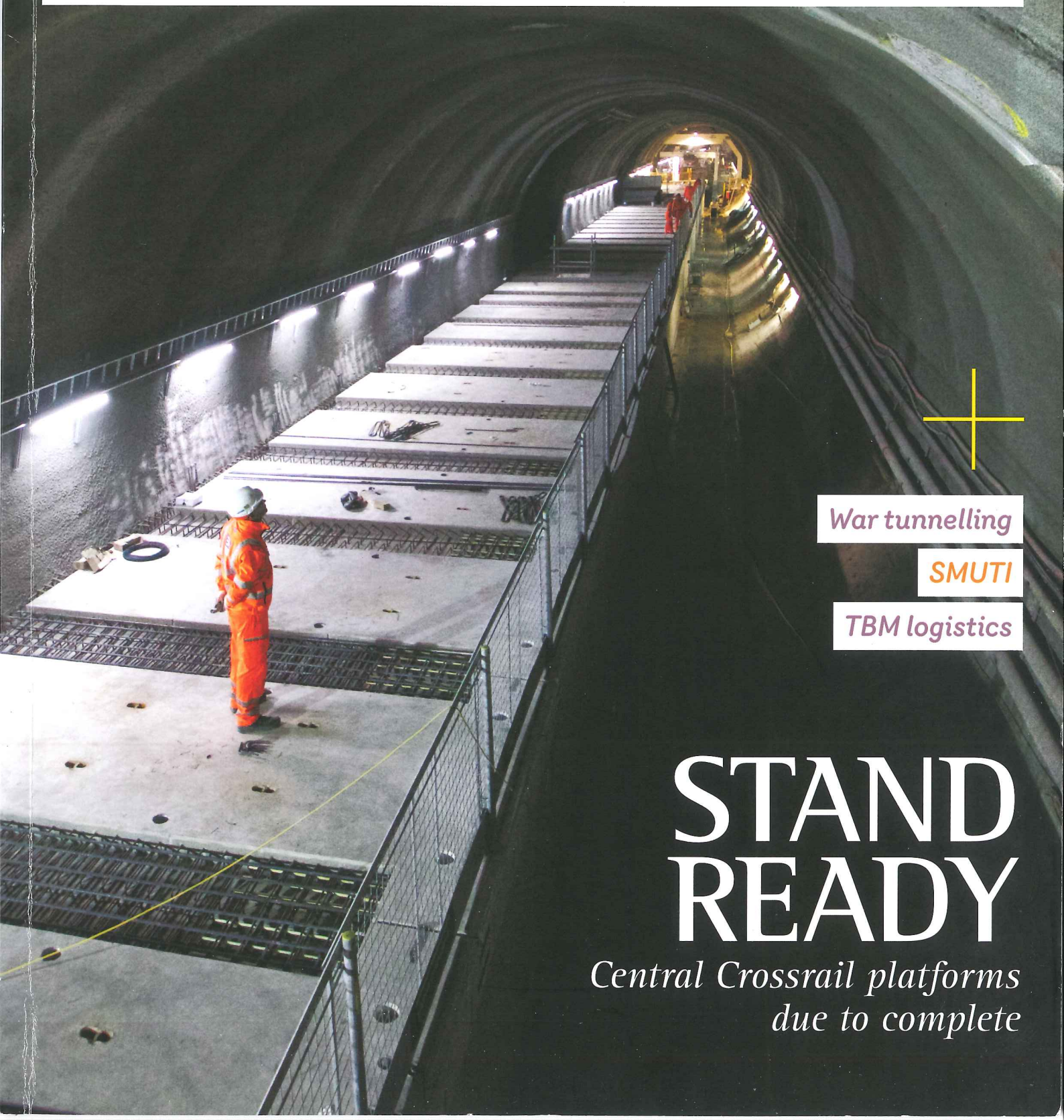
INTERNATIONAL EDITION
August 2016

Tunnels AND TUNNELLING



War tunnelling

SMUTI

TBM logistics

STAND READY

Central Crossrail platforms due to complete

TUNNEL BUZZ

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

SO THE referendum came and went, and the UK looks set to leave the European Union. Emotions are high and column inches long when it comes to the topic so I won't add my reflections on the politics or economics of the situation here. Instead, I will look at the most tangible link between Britain and the continent: the Channel Tunnel. Owner and operator of the link, Eurotunnel, has released a statement in light of the vote to reassure interested parties that it considers its future is still positive as a "motor for development in the UK and continental Europe". It expects to be unaffected by the referendum result and gives the following reasons:

- The Channel Tunnel was established under the Treaty of Canterbury signed 30 years ago by the British and French governments [not an EU treaty]
- The United Kingdom has never been part of the Schengen [EU free movement] area; people and goods travelling through the Channel Tunnel will remain subject to current border control procedures
- A reduction in the value of GBP would reduce the amount of the Group's debt in that currency would increase costs for maritime competitors and would support British exports, which would compensate for any potential negative effects.
- The Channel Tunnel is an important element in the supply chain between the UK and continental Europe.
- The Channel Tunnel provides a "unique level of speed, ease, and security" to the 21 million tourists and business travellers who use it each year.

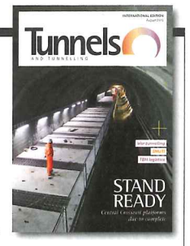
Eurotunnel has expressed fears of a potential rush of migrants trying to pass illegally from France to the UK. Such crossings pose an enormous risk to the lives of migrants, as well as potential risks to passengers, services and damage to equipment.

The rationale is that a post-EU Britain could become excessively isolationist, able to act as it sees fit to keep migrants out of the country. This could potentially, Eurotunnel believes, cause large-scale, frequent attempts on the border before Brexit becomes reality.

According to reports from the BBC and the Independent, Eurotunnel's response has been to increase security, with 500 additional cameras, fences with motion sensors, and now drones equipped with thermal imaging cameras all being used to police the French side of the tunnel. The company does not wish to see another checkpoint at the British portal.

Whether the local French authorities in Calais will tolerate the ongoing migrant disruption is another matter for Eurotunnel to contend with

Cover
This issue's front cover shows a tunnel worker standing inside one of the Crossrail platform tunnels.



Next issue
In the next issue of Tunnels and Tunnelling we have the debut article from the newest member of our team, Paola De Pascali: a spotlight on the Norwegian tunnelling market. Additionally we feature dust control and explosion prevention.

This month...

5 YEARS AGO

Seattle Tunnel Partners announced last month that it has chosen Japan's Hitachi Zosen to supply the 17.7m diameter TBM that will bore the tunnel replacing the Alaskan Way Viaduct. Hitachi Zosen will be responsible for designing, manufacturing, assembling, testing and commissioning the machine, as well as training STP personnel. A press release from the Washington State Department of Transportation said Hitachi Zosen was the "best value manufacturer based on overall technical requirements, support capabilities, price and schedule". TBM proposals were also submitted by Herrenknecht, Kawasaki-Seli, Robbins, and Mitsubishi on 31 May 2011.
Tunnels and Tunnelling, August 2011, p.7

20 YEARS AGO

London and Continental Railways (including Virgin, S G Warburg, Ove Arup, Bechtel, Halcrow, London Electricity, National Express and Systra) has assembled a 500-strong international design and procurement team for the UK's 108km-long Channel Tunnel Rail Link. Project design has been divided into five equivalent value sections: St Pancras; London Tunnels; Thames Valley; Kent; and Systems. Construction is to start in autumn 1997, and tunneling in north London in December 1998. All boring should be complete by 2001 and London's St Pancras station works – including new access subways – by February 2002.
Tunnels and Tunnelling, August 1996, p.7

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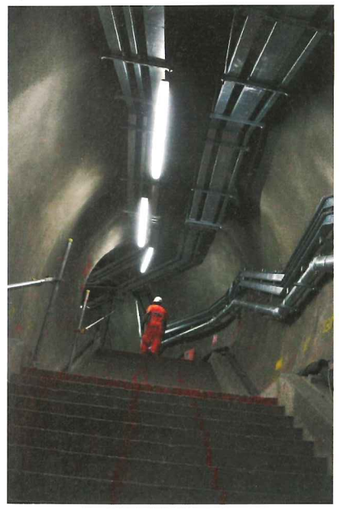

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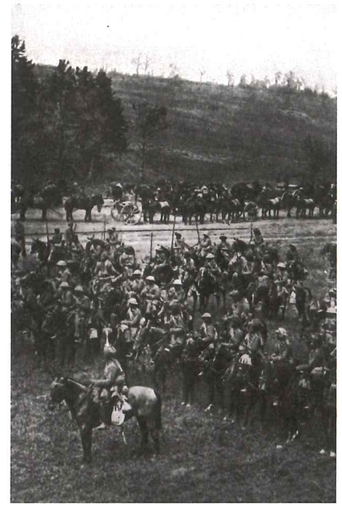

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Key people in this issue

ELENA CHIRIOTTI, INCAS PARTNERS

RAUL FUENTES, LEEDS UNIVERSITY

JAMIE STANDING, IMPERIAL COLLEGE

MIKE BLACK, CROSSRAIL

NICK BUENFIELD, IMPERIAL COLLEGE

MOHAMMED ELSHAFIE, CAMBRIDGE

BENOIT JONES, CAMBRIDGE

ALAN BLOODWORTH, WARWICK UNIVERSITY

ALEC MARSHALL, NOTT'M GEOMECHANICS

TBM MANUFACTURERS TO MERGE

INTERNATIONAL — Robbins and Northern Heavy Industries (NHI) agreed to a three-phase merger plan on 28 June. Initially the Shenyang based heavy machinery giant will take a minority interest in Robbins. Following this, probably in July 2016, NHI will take a 61 per cent stake in the American TBM manufacturer.

Finally Robbins, NFM (which NHI merged with in 2007) and NHI will be fully merged "combining their collective resources and expertise". Details on this were expected in July as Tunnels and Tunnelling went to print. It is expected that the new entity will comprise some 2,000 employees.

According to a Robbins spokesperson, Lok Home will remain as leader of the company for now, and will become president of the newly created Robbins-NFM-NHI entity. Management and operations at the Robbins company are expected to continue as usual.

"This merger puts Robbins in an excellent position to expand our presence in the global TBM market," said Home. "It will enable us to provide better global service and support to our customers, and will open the door to new opportunities, especially in China. NHI has very impressive capabilities. Joining forces with them gives us expanded resources to go after more projects and strengthens our reputation as a world leader in the tunnel boring industry."

According to Robbins, this is a general strategy considering the business environment for TBMs in China; and worldwide. It has been discussed for nearly 5 years and seriously put in place in the last year.

Based in Shenyang, NHI employs 10,000 people and is among China's top three heavy machinery manufacturers. Its products are sold to more than 30 countries worldwide.

Money secured for Virginia rail tunnel refurbishment

USA — The Commonwealth of Virginia Transportation Board approved in June USD 1.3M in funding to restore a long-abandoned, historic railway tunnel located in Central Virginia's Blue Ridge Mountains.

The Claudius Crozet Blue Ridge Tunnel Foundation - a regional public-private partnership - has been working toward the restoration, preservation, and interpretation of the Blue Ridge Tunnel. The group is named for the engineer, Claudius Crozet (1789-1864), who led the tunnel project and whose "professional expertise and visionary leadership were essential to the establishment of a railroad infrastructure across Virginia, instead of a widely preferred system of canals."

The money will go toward phases 2 and 3 of the project, completing the restoration of the tunnel, the construction of the pedestrian/biking trail within the tunnel, and final construction of trailheads and trails to both the east portal (started in Phase 1) and the west portal of the Blue Ridge Tunnel.

Nelson County completed Phase 1 of its Blue Ridge Tunnel Project in late June 2015, which included a substantial completion of the eastern trail and parking lot, and fencing the length of the trail as a barrier to the active rail line next to it.

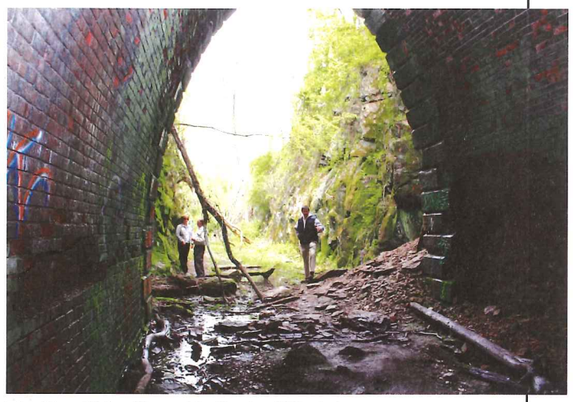
Stephen Carter, Nelson County administrator, explained the rehabilitation of the tunnel includes removal of two concrete bulkheads that were installed in the 1950s in a failed natural gas storage project. The tunnel was abandoned by C&O Railroad, now CSX Corp., in the 1940s.

"The removal of the two bulkheads is a significant component of the restoration of the tunnel and its conversion to a public hiking trail," he said. "Additional work within the tunnel includes restoration of the brick casement that lines about 1,400ft of the tunnel from the tunnel's western portal in Augusta County proceeding to the bulkhead on this side of the tunnel."

A series of rock bolts will also be installed in the tunnel, as previously determined by the structural engineering sub-consultant to the project's lead engineering consultant firm. Additional rock bolts may also be installed, as determined by the structural engineering sub-consultant, once the actual construction project is in process. The tunnel Project will also provide for construction/installation of the trail surface within the tunnel, removal of graffiti, etc.

Carter said, "it is the County's objective to issue one sealed bid request for completion of the overall Tunnel Project."

A specific date is still to be determined.



The Blue Ridge Tunnel in Central Virginia

The Blue Ridge Tunnel opened in 1858 to allow rail access through Afton Mountain. The 4,273ft (1,302m) passage took nearly nine years to construct and was the longest tunnel in the US at the time. According to the foundation: "the tunnel was constructed at a depth of 700ft below the ridgeline at Rockfish Gap. The geology of the Blue Ridge at Rockfish Gap - especially on the eastern (Piedmont) side - consists of greenstone that is, 'as hard as can well be conceived,' in Crozet's words. Several of Crozet's letters to the Board of Public Works referenced the rock's 'excessive hardness.'"

On December 29, 1856, labourers from the east end and the west end holed through, meeting within inches of Crozet's centreline alignment.

"Crozet also implemented innovative solutions for the tunnel's construction, including smoke-removal ventilation systems powered by mules on treadmills as well as the world's longest siphon (which removed an average of 60 gallons of water each minute)," according to the foundations. "The contracting firm of Kelley & Larguey utilized construction crews comprised mostly of Irish labourers as well as several dozen slaves. Averaging 26.5ft of progress per month, the crews simultaneously excavated the tunnel from each end using only hand tools and black powder."

The Blue Ridge tunnel was taken out of service in 1944.

Virginia's Midtown Tunnel opens to traffic

USA — The Elizabeth River Tunnels (ERT) Project Team, comprised of Elizabeth River Crossings OpCo, LLC (ERC), SKW Constructors, JV (SKW) and the Virginia Department of Transportation (VDOT), opened one lane of the new, immersed Midtown Tunnel under the Elizabeth River on June 17.

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 in the region and rely on Virginia's existing Midtown Tunnel, which carries more than one million vehicles per month.

Longer Yarraville tunnel option selected

AUSTRALIA — The reference design for Melbourne's second river crossing was released on 10 July. The design opted for the longer of two tunnel proposals, a 1.6km twin tunnel at 15.5m diameter. Public opinion against the destruction of surface green space in the Yaraville neighbourhood prompted the decision.

The tender process has begun and impact assessments will soon get underway. Studies will be available to view in early 2017. The construction contract should be awarded in late 2017 with construction to start soon after. Construction is expected to complete in 2022.

Three consortia have been shortlisted to bid for the project: John Holland and CPB Contractors; Lend Lease Engineering and Bouygues Construction; Salini Impreglio, Fluor Australia and Lane Worldwide Infrastructure.

The contractors will prepare fully costed designs for the Western Distributor, which includes the widening of the West Gate Freeway, a tunnel under Yarraville, a second river crossing, and connections to the port, CityLink and the city. The entire project will cost AUD 5.5bn (USD 4.2bn).

Calgary tunnel choice

CANADA — The Green Line LRT project team completed the first stage of evaluation for the project's Centre City alignment, and announced its recommendation for a full tunnel on April 18.

The project team considered five options, ranging from the full tunnel to a variety of combinations with elevated and at grade routes. The Green Line LRT will connect from the Inglewood/Ramsay area in the southeast to Crescent Heights/Mount Pleasant in the north, via the Beltline and downtown core. The transition from downtown to the north segment of the line requires the LRT to cross the Bow River to connect with Centre Street North.

The results of the evaluation show that Option D best meets these criteria. This option would see the Green Line LRT run underground from the Beltline (Beltline route is yet to be determined), under 2 Street S.W., and under the Bow River. The line would resurface at approximately 20 Avenue and Centre Street N.

The city said, "while the underground option was the highest ranked in the evaluation process, further analysis is required before the project team takes a formal recommendation to Council within the next year. Technical design, economic analysis and further discussions with the public will inform the official recommendation."

The Green Line's route in the Beltline will undergo a similar evaluation process. The Green Line team will evaluate underground, street-level or elevated guideway.

Calgary's mayor, Naheed Nenshi, previously said he wants construction on the north-south line to begin in 2017, with completion by 2024. The project will double the city's LRT system, adding 40km of track to the existing 59km LRT network. In January 2014, Calgary's City Council approved funding of CAD 520M (USD 401.5M).

VDMA VOICES BREXIT NERVES FOLLOWING UK VOTE

GERMANY — The VDMA, a mechanical engineering association, has expressed concern over the British decision to exit the European Union (EU). In a statement the organisation said it feared a loss of confidence in Europe as an industrial location and a drastic reduction of exports to the UK. And Germany is particular is losing a key ally in economic terms.

In 2015, the UK was the fourth-largest foreign market EUR 7.2bn (USD 7.96bn) for Germany's mechanical engineering sector, behind the USA EUR 16.8bn (USD 18.58bn), China EUR 16bn (USD 17.69bn) and France EUR 9.8bn (USD 10.84bn).

"Great Britain's decision to leave the EU is a warning signal for companies. The Brexit will cost Europe as an industrial location a great deal of confidence among investors," said Thilo Brodtmann, VDMA chief executive. "It won't be long before our machinery exports to the UK start to fall off noticeably. It is [also] completely unclear what will happen to companies with UK subsidiaries.

"The EU must now contain the damage and keep the period of uncertainty as short as possible. Europe's companies need security to plan ahead and a reliable roadmap for the exit. For export-oriented companies, fragmentation of Europe would be the nightmare scenario."

Brodtmann however has no doubt about the future viability of the EU.

As Tunnels and Tunnelling goes to press, the IMF had slashed growth rates in Western Europe, with France, Germany and Britain all at around 1.2%.

Thilo Brodtmann

BREAKTHROUGH ON UKPN TUNNEL

GREAT BRITAIN — A 3km UK Power Networks (UKPN) tunnel has broken through in Tower Hamlets, east London. J. Murphy & Sons excavated the GBP 27M (USD 36M) 2.85m-diameter tunnel at a depth of 23-30m.

Geology along the alignment was the full range for London from heavy London Blue Clay, Lambeth Group, Thanet Sands and into the chalk, containing flints at the deepest levels.

A spokesperson for Murphy said: "Murphy broke through to the final tunnel reception chamber in Tower Hamlets in east London, right on target - having allowed for a variance of just 50 millimetres from the start of the tunnel in Southwark, south-east London. The Murphy team selected the company-owned Lovat tunnel boring machine Fionnuala, a 91-tonne machine built to Murphy's specifications. Fionnuala's components were first lowered into the tunnel chamber in south-east London in August 2014 in three main sections, taking two weeks to build below ground and has since progressed at a highly impressive rate of 23 metres per day, with up to 3bar external water pressure."

The tunnel connects substations north and south of the River Thames to meet London's demand for electricity. By choosing to tunnel from one substation to the other, Londoners avoided months of disruptive roadworks for cable installation, upgrades or repairs.

The Murphy team will now spend two weeks taking Fionnuala apart onto 70m of back-up sledges, guiding all the equipment through a custom-sized junction chamber in Tower Hamlets before lifting her out of a shaft using a 350 tonne mobile crane.

The tunnel will now be lined with hundreds of cable support brackets to carry 132,000 volt electricity cables, connecting substations between south-east London, the City and east London. Work to fit out the new tunnel will start in July and last seven months. The new cables are due to go live next summer.

Project facts

- The work involved over 290,000 man hours - all achieved without any lost injury time, a result of the Murphy safety culture development programme and "Never Harm" ethos
- 2,965m tunnel comprises of 17,790 individual segment linings weighing 750kg
- Over 77,000 tonnes of excavated material have been transported from site
- 99.7 % of surplus material removed from site has been recycled
- Over 2,600 tonnes of cementitious grout have been injected behind tunnel linings
- Crossed under 'live' operational Jubilee lines with no settlement, plus crossed under the Thames
- Carried out three 'free-air' tunnel boring machine interventions to inspect the cutter-head, a process that takes 4 days and nights, replacing the teeth and picks to work at maximum efficiency

TBM components arrive in Atlanta for Bellwood Quarry tunnel project

USA — The main beam of a Robbins TBM arrived in Atlanta on June 29 for assembly at the Bellwood Quarry, where a USD 270M project will build a 5-mile- (8km-) long tunnel connecting the Chattahoochee River and flooding the former rock quarry.

The 12.5ft (3.8m) diameter TBM will arrive over the next month in shipments from Ohio and will be assembled at the bottom of the quarry.

A concrete liner will be installed for the 10ft (3m) diameter tunnel, which will create a 30-day raw water storage vessel whereas there is currently only a three-day supply.

The project will include new pump stations to draw water through the tunnel, which would be approximately 10ft (3m) in diameter and 200ft (61m) below ground, connecting to the Hemphill Water Treatment Plant and the quarry.

Work also includes replacing aging water transmission lines that are still in service. Cast iron mains of diameters 30", 36", and 48" were installed in 1893, 1908, and 1924 respectively.

"Although these were renewed with a cement liner in the 1950s, they have far exceeded their design life. A fourth line, 72" steel main, was built in 1975 and metallurgical weaknesses restrict its operation to warm weather months," according to the City of Atlanta's Department of Watershed Management.

The council authorised a construction manager at Risk contract with PC Construction/H.J. Russell & Company on June 1, 2015. Atkinson Construction secured the USD 81M contract for the Atlanta Water Supply Program Phase 1 Extension in February. Work includes construction of four shafts; approximately 1,000lft of adit connections joining the shafts; the main 400ft deep tunnel; and another five additional small-diameter well shafts at the Hemphill site.

Institution of Engineering and Technology announces new deputy and president-elect

GREAT BRITAIN — The Institution of Engineering and Technology (IET) has announced that Professor Jeremy Watson will become its next President, taking up the position on 1 October.

Watson is Professor of Engineering Systems and Vice-Dean in the Faculty of Engineering Sciences at University College London.

He is also Chief Scientist and Engineer at BRE. Previously, Jeremy was Chief Scientific Advisor for the Department of Communities & Local Government and Arup's Global Research Director.

Jeremy was awarded a CBE in the Queen's 2013 Birthday honours for services to engineering.

Jeremy Watson

Additionally Mike Carr became IET Deputy President. Until November 2008 Carr was BT's Chief Science Officer, and responsible for the company's world-leading Research Labs and Commercial Exploitation Unit. More recently he has been a Council Member of the EPSRC, a Board member of Innovate UK and a previous Vice President of the IET. He currently serves as a Non-Executive Director of Ordnance Survey and for Ploughshare Innovations.

The IET is one of the world's largest engineering institutions with 167,000 members in 150 countries.

SCL exclusion zones guidance now available

GREAT BRITAIN — The new best practice guide for SCL exclusion zone management is available from the BTS website. Produced in collaboration by Crossrail, BFK, BBMV, DSJV, Costain-Skanska and Hochtief-Murphy, with support from the BTS, the aim of the document is to "provide guidance on the consistent application of control measures to be used on Crossrail sites in the management of exclusion zones and restricted areas around active working areas in tunnels employing the Sprayed Concrete Lining (SCL) methodology".

Exclusion zones guideance

The guide was reproduced in full in last month's issue of Tunnels and Tunnelling, complete with a foreword from the immediate past chair of the BTS, Roger Bridge.

To find all of the best practice guidance available on the BTS website, visit: www.britishtunnelling.org then click the 'Knowledge' tab at the top of the page.

Anglesea pipeline completed successfully

AUSTRALIA — Herrenknecht recently released a report on one of its Australian small bore projects. The job, which required the installation of a 700m-long 355mm-diameter HDPE pipeline in Anglesea, Victoria saw contractor Dunstans Construction employ an HDD rig from the German manufacturer capable of pulling 250t and producing torque of 90kNm.

The pipe was a sewage outfall from a treatment plant for client Barwon Water, which was made necessary by a rockfall in 2015 that disrupted existing infrastructure. Local geology was mudstone.

A spokesman for Herrenknecht elaborated on the process: "The crew first drilled a pilot hole from the treatment plant to the coast and under the sea. Then, the borehole was reamed from the land side. After completion of the borehole Dunstans overcame another hurdle presented by the project: transporting the 700 m long product pipe by sea past Port Philip Bay, one of the busiest ports in Australia. Regular shipping was not obstructed by the exceptionally long cargo.

"To complete the installation Dunstans pulled the pipeline floating on the sea through the predrilled alignment all the way back to the treatment plant. Thanks to the 250 tonne pulling force of the HDD Rig this task was carried out quickly and cleanly. With the connection of the pipeline to the treatment plant completed before Christmas, Anglesea was ready for the tourism high season in summer."

Singapore to call for DTSS tenders

SINGAPORE — The national water agency (PUB) and the National Environment Agency of Singapore (NEA), will be calling tenders from this year onwards for the Deep Tunnel Sewerage System (DTSS) Phase 2 and the Integrated Waste Management Facility (IWMF) to spearhead the implementation of Singapore's used water and solid waste management solutions.

DTSS Phase 2, which includes enhanced deep tunnels with advanced sensing and maintenance features, associated link sewers, Tuas Water Reclamation Plant (TWRP) and integrated NEWater factory, is estimated to cost some SGD 6.5bn (USD 4.8bn). With a total treatment capacity of 800,000 cubic metres per day, TWRP will also be the largest membrane bioreactor facility in the world. Currently at the detailed design milestone of the project, PUB will be calling for consultancy and construction tenders for the various project components in phases beginning from Q3 2016.

CROSSRAIL 2 PUBLIC CONCERNS ADDRESSED

GREAT BRITAIN — Transport for London and Network Rail published their response to a recent Crossrail 2 public consultation.

The consultation was launched jointly by TfL and Network Rail last year. It received nearly 21,000 responses on 40 issues including: Station locations, entrances and exits for the tunnelled section of the proposed route, locations of ventilation shafts for the tunnelled section, construction sites required to build the scheme, service patterns and changes to existing National Rail services.

The full report can be viewed here: https://consultations.tfl.gov.uk/crossrail2/october2015/user_uploads/rtir.pdf

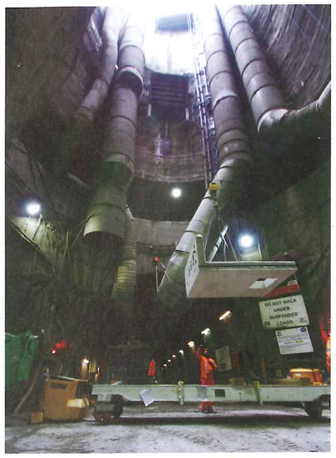
Specific concerns highlighted by TfL include:

- Dalston - Concerns were raised about the impact of works on Bradbury Street and Ridley Road market. TfL is assessing the feasibility of an option which could integrate the Crossrail 2 entrance into the Kingsland Shopping Centre, reducing the impact on Bradbury Street
- Angel - Residents raised concerns about the loss of important buildings in the area. Crossrail 2 engineers have updated the design to reduce the size of a planned worksite at Chapel Market/White Lion Street. TfL is also investigating an option to improve pedestrian access around the station, specifically creating a link to the station via Torrens Street.
- Clapham Junction - Following people's suggestions, Transport for London is looking at the possibility of an additional entrance on St John's Hill, which would improve access.
- Alexandra Park - People voiced concerns about the loss of green space and the impact on Avenue Gardens. Crossrail 2 engineers have now found a solution to make the worksite concerned smaller.

A spokesperson for TfL added: "Crossrail 2 will connect National Rail networks in Surrey and Hertfordshire with an underground tunnel beneath central London between Wimbledon and Tottenham Hale and New Southgate. It will relieve pressure on the transport network across London and the South East.

"TfL and Network Rail are now working with the Department for Transport to develop Crossrail 2 ahead of further public consultation expected to take place this autumn. Subject to delivering on key recommendations made from the National Infrastructure Commission, a Hybrid Bill could be submitted in 2019 which could enable construction starting in the early 2020s, with the first Crossrail 2 service running in 2033."

LIVERPOOL STREET PLATFORMS COMPLETE




Tunnel access and platform works at Liverpool Street Station

GREAT BRITAIN — The Liverpool Street Station platforms have been completed. The milestone marks the completion of all central station platforms on London's Crossrail project. Whitechapel platforms were still ongoing as Tunnels and Tunnelling went to print.

The two 240 metre long platforms, constructed as part of the Crossrail programme, were pre-fabricated in more than 500 pieces at a factory over 200km away near Sheffield. They were then transported to London, lowered down the station's main shaft and pieced together below ground.

The new platforms have taken around four months to install and are around twice the length of many existing London Underground platforms to accommodate the new 200 metre long Elizabeth line trains.

The Crossrail project is approaching 75 per cent complete and is being delivered on time and on budget. The project is now focussed on the complex job of fitting out the stations and tunnels with the equipment and systems needed to operate the railway.

Nearly 4km of platforms have been constructed at stations in central London. The platforms are now complete at all stations from Paddington to Woolwich apart from Whitechapel where construction is ongoing.

The Elizabeth line station at Liverpool Street will open in December 2018 when two fully accessible ticket halls will provide an interchange with Liverpool Street to Shenfield services, the Northern, Central, Metropolitan, Circle and Hammersmith & City lines, as well as National Rail services. An estimated 124,000 passengers will use the station every day.

Alaskan Way TBM finishes maintenance stop

USA — Seattle Tunnel Partners (STP) resumed mining on July 18 following a month of routine and hyperbaric maintenance on the TBM mining the SR99 tunnel, the Washington Department of Transportation said (WSDOT).

Crews inspected and repaired machine components as needed during the maintenance period, which started on June 23. WSDOT said the maintenance period included more than 40 shifts of work under hyperbaric conditions, changing cutting tools and performing other maintenance in the space behind the cutterhead. In all, STP changed 33 of more than 700 cutting tools.

Tunnelling is one-third complete. The machine is currently approximately 120ft (36.6m) deep and will eventually reach a depth of 200ft (60m) along its alignment. STP expects to stop two more times for maintenance before they reach the future north portal.

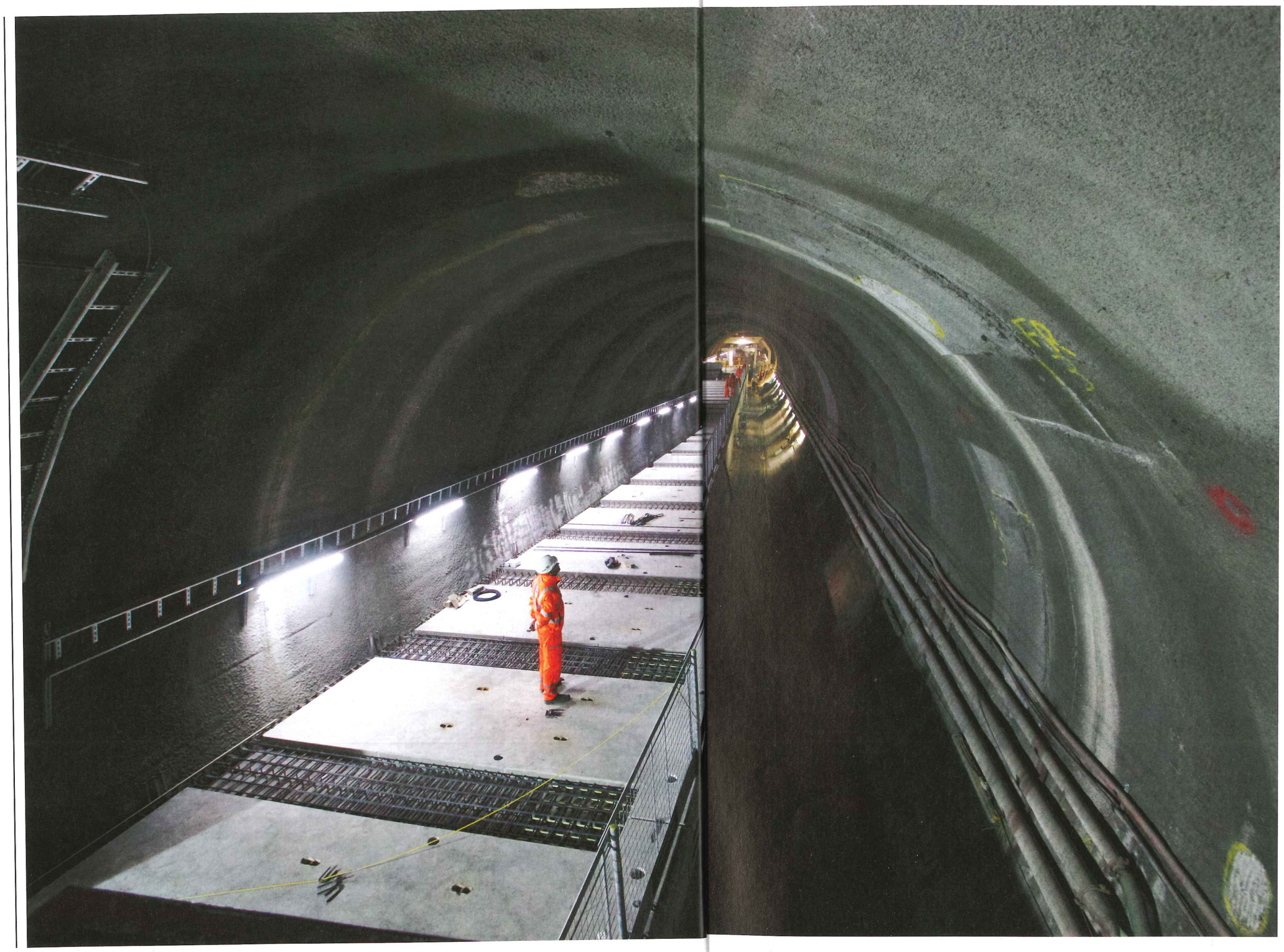

Photo of tunnel posted after the maintenance stop

Sewer collapse in South London

GREAT BRITAIN — A large hole that disrupted train services in South London turned out to be caused by a collapsed Thames Water Sewer.

As Tunnels and Tunnelling went to press the cause of the collapse was unknown, but temporary pumps had been put in place to divert the flow of the sewer and allow the resumption of train services in the area.

Repair works will be a difficult operation according to client engineers as the sewer is located 6m directly below the track. Network Rail area director Paul Rutter said: "Following investigations, a collapsed sewer has been found at the site of the hole which was found on the railway in the Forest Hill area yesterday. Network Rail engineers have been working with our counterparts at Thames Water throughout the night to identify and fix this problem as quickly and as safely as possible."



Left: A worker inspects the platform tunnel at Liverpool Street in London

FRC SEGMENT PRACTICE

Elena Chiriotti
Elena is WG2 animateur and co-founder of Incas Partners, a Paris-based consultancy

AT WTC 2016 in San Francisco, ITA's Working Group 2 – Research published a document entitled Twenty Years of FRC Tunnel Segments Practice: Lessons Learnt and Proposed Design Principles.

The document was conceptually agreed during the 2009 meeting of WG2 in Budapest and was promoted by the former animateurs Eric Leca of France, Chungsik Yoo of Korea, and the current animator Elena Chiriotti from France. An early draft document was presented in Vancouver in 2010. A revision was approved this year.

In the last two decades, the use of FRC progressed and was adopted for several tunnel projects. Among the benefits related to the use of fibre reinforcement in cementitious composites, the most important are the noticeable increase of toughness – that is the post-cracking tensile residual strength, which enhances the resistance to crack development – and the possibility to optimise the reinforcement for controlling diffused stresses. FRC can be combined with reinforcing bars where high localised stresses occur, and the use of fibres facilitates the production process.

The enhancement of the general structural behaviour together with the improvement of the industrialised production of precast tunnel segments are probably the two key factors in the continuous growth of using FRC in precast tunnel linings.

The aim of the document prepared by WG2 is to provide advances in the design of FRC tunnel lining in accordance with the objectives of the International Tunnelling and Underground Space Association (ITA) prescribed in Section II of its Statutes (ITA, 1976). Standards and recommendations related to the properties of FRC, to the design of general FRC elements (mainly slabs or beams), and some recommendations on FRC for tunnel lining (mainly limited to steel fibre reinforced concrete) are already available (Figure 1). Such documents generally do not provide details on specific requirements and loading conditions applicable.

The document proposes a brief overview on current available applicable standards for the characterisation of FRC's fracture properties and for the design of FRC elements. Among them, the new FIB Model Code 2010 is mentioned, which refers to EN 14651 for determining the main significant residual post-cracking strengths. The well-known Model Code 2010 provides general design rules that can be easily applied for typical structures such as beams or slabs, but they need to be contextualised to the specific issues concerning tunnel lining elements. The lining segments are, for instance, characterised by a temporary loading condition during the excavation of the tunnel, where considerable localised stresses act on the lining due to high concentrated forces exerted by the TBM's hydraulic jack (TBM thrust phase). The noticeable enhancement of post-cracking residual strengths due to the addition of fibres can be exploited during this stage even if no specific recommendations are included in Model Code 2010.

The document takes advantage of 20 years of FRC practice in precast tunnel lining - including research and feedback from more than 70 real cases – to provide a guide to complete the existing standards and recommendations for the specific case of tunnel lining. More specifically, the scope includes:

- Supporting a performance–based design approach for FRC structural elements, which allows all fibres meeting requirements for long-term behaviour to be considered for structural applications;
- Detailing the results of recent research advancements in the field;
- Providing additional design principles to complete the existing standards and recommendations, in particular with regards to the loading conditions and design procedure;
- Giving specific advice on analytical and numerical procedures necessary and adequate to quantify, during the design process, the beneficial effects of fibres.

The quantification of toughness provided by fibre reinforcement is of paramount importance for the definition of rules and recommendations for the design of FRC structural elements, since the classical design, based on the elastic approach, is acceptable only for ordinary reinforced concrete structures. A proper design procedure that takes into account the significant residual tensile strength provided by fibres after cracking has to be adopted in case of FRC structural elements. In particular, the cracking phenomena of concrete matrices containing fibres can be accurately represented by using an approach based on non-linear fracture mechanics.

In the document special attention is devoted to some particular loading conditions that, based on experience, should be considered since they can be very severe for a tunnel segment reinforcement solution based on fibres only. As an example, the case of loads generated on the already installed lining segments during the TBM thrust phase should be analysed at both a local and a global scale.

The local behaviour regards the analysis of the tensile transverse stresses (splitting or bursting stresses perpendicular to the loading direction). Specific experimental tests prove that FRC enables a stable propagation of cracks compared to plain concrete. However, appropriate design tools have been used in order to properly model and consider this aspect. Such tools include non-linear numerical analyses and experimental tests.

The global behaviour concerns considering the possible irregularities of contact among adjacent segments, which can be due to an eccentricity of the thrust shoes, to an uneven support, etc. FRC tunnel segments with fibres only are more vulnerable to irregular load conditions, since this generates increased localised stresses. At the design stage, specific attention has to be paid to the type and probable occurrence of such irregularities; to consider and properly model different boundary conditions for the segments.

The WG2 document proposes a step-by-step approach based on numerical analyses consisting of:

- Simplified 2D non-linear numerical models of local conditions on a single segment,
- 2D non-linear numerical models of a group of segments, including different boundary conditions for modelling the possible irregularities of contact,
- 3D advanced segment models.

It is recommended that the three steps are carried out systematically, and that the use of 3D models is subordinated to the previous understanding of the phenomena through simpler models.

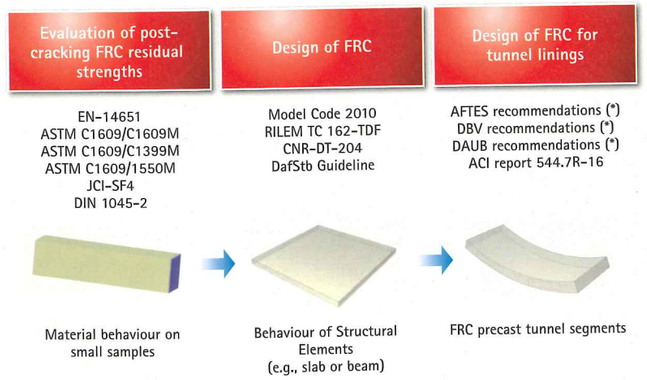
In addition, experimental tests on small samples (for the local behaviour) or full-scale tunnel elements (for the local and global behaviour) are recommended as useful tools for proving the design approach. However, they should not substitute a robust design approach.

Since localised stresses are better resisted by localised reinforcement, such as traditional steel rebars, while diffused stresses are better resisted by spread reinforcement, such as fibres, depending on FRC properties, lining geometry and ground-conditions, the proposed design approach allows achieving and optimising design solutions that could be based on fibres only or fibres plus traditional rebar (hybrid solution) when needed.

The author would like to take advantage of this space to acknowledge the members of the WG2 who have prepared and reviewed the document, ITA Ex Co for leading the review process and ITAtech Support, Sub AG PFRCS for their useful feedback

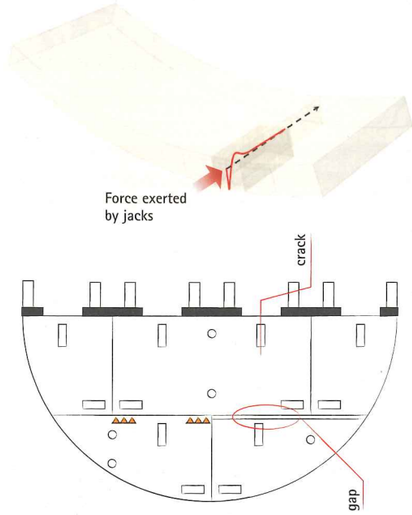
Working Group 2

ITA's Working Group 2 (WG2) has been active for many years and is one of the best attended working groups at each WTC. A consistent and stable group of engineers coming from the major international design firms, the academic world and the industry are actively participating, including international experts who have contribute in preparing norms such as Eurocodes, FIB, and ACI on fibre reinforced concrete (FRC).

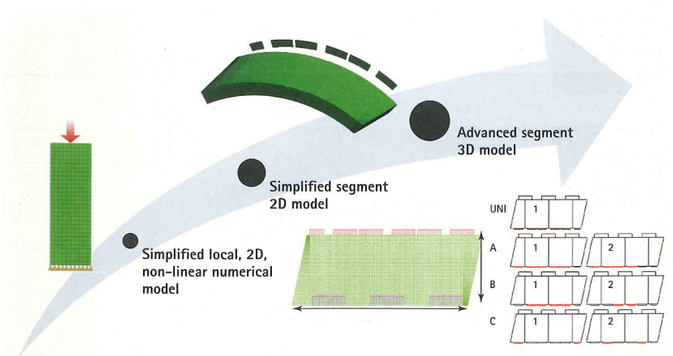


Below: Figure 1, State of major standards and recommendations related to the design of FRC elements

(*) refers only to the Design SteeL Fibre Reinforced Concrete (SFRC)



Above: Figure 2, Local (upper image) and global (lower image) behaviour of tunnel lining segments



Below: Figure 3, Proposed step-by-step approach based on non-linear numerical analyses

ALL ACADEMIC?

Research from academics in UK institutions is improving understanding of tunnels and the effects of building them, making construction more cost efficient and tunnels safer all over the world. **Bernadette Ballantyne** reports

Bernadette Ballantyne
Bernadette is a longstanding regular contributor to *Tunnels and Tunelling*

WHEN CONSIDERING the cumulative effect of repeated seismic loading from earthquakes on tunnels one may not immediately think to speak with researchers at Leeds University's Institute for Resilient Infrastructure. However this is exactly where world leading research into understanding tunnel behaviour is taking place. Under the "Shaking Tunnel Vision" project, financed by the UK's Department for International Development (DfID) Newton Fund, Associate Raul Fuentes is leading a two year project monitoring and modelling two major tunnels in Chile. "Data from the US geological survey website told us that there is a surprisingly huge number of earthquakes affecting Chile," says Fuentes. "It revealed over 200 within 100km of Valparaiso with a magnitude higher than 4.0 and 17 higher than 5 only in a period of two years. It was an astonishing amount," he says.

A road tunnel in the coastal city of Valparaiso will host one of the studies, with the other situated in a metro tunnel in the capital Santiago. At each location 50 instruments – 25 tri-axial accelerometers and 25 inertial measurement units will record the acceleration profile and deformation over the two years of the study and will remain in the long term. The data will then be fed as a live stream to an online portal which will be analysed by the research team and made publically available.

The project also involves creating numerical models that will be validated as the data is collected so as well as improving understanding of tunnel behaviour under repeated seismic loading, the study will also enable the development of engineering risk based disaster management approach for tunnels in seismic areas. A third strand to the project is the creation of a new case study that will act as in internationally recognised reference point for improved

Metro line extension running tunnels in Chile

design approaches.

"Design codes require that tunnels are designed to withstand large earthquakes but nobody has been interested in what happens to tunnels when you have multiple smaller earthquakes happening repeatedly. There is anecdotal evidence of cumulative damage of multiple earthquakes but it normally gets sorted out with smaller repairs and no one has done a systematic study," says Fuentes.

Although Fuentes is the Principal Investigator, the University of Leeds is also working with the University of Dundee, the National University of Athens, ETH Zurich and the Pontificia Universidad Catolica de Valparaiso in Chile on the study.

Above: The Royal Mail Tunnel

Below: Aerial view of half scale full rig test set up (red outer ring provides load reaction for actuators)

Meeting on site in Chile in April enabled all parties, including the companies that manage the tunnels, to understand the research team objectives and there is huge interest in the potential findings which could, of course, could go either way. Tunnels may be so overdesigned already that the cumulative seismic effect is negligible over the lifetime of the structure. "But the answer may be that we observe some damage so then we will have to go back to square one in terms of what the codes say as at the moment they actually don't say anything on cumulative effect," says Fuentes.

At the same time the monitoring systems are set to give new data about critical assets and there is potential for the scope of work to expand further with over 200 tunnels in Chile that could benefit from monitoring systems.

LONDON CALLING

Imperial College London has been actively carrying out research into ground and structural response to tunnelling for more than twenty years through field monitoring, numerical analysis and model testing. Following major field monitoring campaigns on the JLE (Jubilee Line Extension) and CTRL the latest focus has been to investigate the response of existing tunnels to new tunnel construction. Field monitoring was used to assess the effect of building the new 7.1m diameter tunnels of the east-west Crossrail link on the existing Central Line underground railway tunnels. This major study was financed by the UK Engineering and Physical Science Research Council (EPSRC) with contributions from Crossrail Ltd, Morgan Sindall and collaboration with London Underground Limited. "It had five primary strings to it," explains Principal Investigator Jamie Standing, Reader in Ground Engineering the Civil and Environmental Engineering Department of Imperial College London. "Field monitoring; structural testing on half-scale cast iron segmental rings; numerical analysis of field conditions; numerical analysis of the laboratory set-up and a comprehensive suite of tests on London Clay from high quality samples taken when installing the field instrumentation in Hyde Park. These strands linked together very closely," he says noting that the numerical analysis was led by David Potts using the bespoke software ICFEP.

The existing Central Line tunnels were constructed from grey cast iron segmental tunnel linings, which are prevalent in many developed cities throughout the world. The results therefore offer lessons for many future schemes. "It taught us a lot," says Mike Black, head of geotechnical engineering and lead on research papers for Crossrail Ltd. "We were assessing the ground interaction effect with this cast iron structure and understanding how that may have performed itself over time prior to Crossrail work, and subsequently the effect that Crossrail would have on that structure," he says explaining that the combination of field measurements thorough extensive instrumentation, laboratory analysis and numerical analysis enabled these different aspects to be compared with one another.

"The findings should be very useful to future projects," says Standing, noting that several papers have been produced from the study and others are still being written up. "Examples of key findings are that it is often thought that rings articulate but in the case of the Central Line tunnels just east of Lancaster Gate, where Crossrail ran 4.2m below the existing line, we found that all the longitudinal straining took place in the iron itself and not in the joints which is an important finding." Another important aspect of the project was the study of bending moment distributions around the existing tunnel. "We have investigated carefully the Morgan Equation and Muir Wood's modified version and have gained insight into how well they have worked from the structural testing that we did," says Standing.

The approach used in this project is typical of how the Geotechnics Section at Imperial College works: validating numerical analyses with results from fieldwork and feeding in parameters determined from advanced laboratory studies.

More recently there has been a focus on using the ground as a medium for storing thermal energy as a means of supplying sustainable, renewable and low-carbon heating and cooling to buildings. "Particular emphasis has been placed on the use of geotechnical structures, such as tunnel linings, as heat exchangers," says David Taborda. "The associated temperature changes have the potential to generate additional ground movements, as well as structural forces, and are being investigated using newly commissioned laboratory equipment and newly implemented thermo-hydro-mechanical algorithms within ICFEP."

Structural testing also features in the work of Nick Buenfield, head of civil engineering at Imperial College, who specializes in the long-term durability of concrete structures. Concrete-lined metro tunnels are particular interest as these are usually exposed to groundwater on the external face and drying conditions inside, causing aggressive contaminants in the groundwater to penetrate the concrete.

On the materials side Chris Cheeseman has been focussing on the reuse of waste materials, the circular economy and low-carbon cement and concrete, most notably discovering that heating waste London clay to temperatures of over 800 °C transforms it into a highly reactive pozzolan. This then has potential to be processed to form a technically and commercially viable supplementary cementitious material that could compete against ground granulated blast furnace slag and coal fly ash for use in concrete.

Safety too has been a key research area with Tim Newman's PhD research looking into causes of confined space hypoxia during underground construction in the Lambeth Group beneath London in conjunction with ground investigations for the Thames Tideway project. A major finding was that glauconite cannot cause the oxygen loss. Another mineral, green rust, has been identified as a potent and plausible reducing agent.

MEASURING MORE

Imperial College is not the only University to undertake research on London's Crossrail project. At Cambridge research on the project began in 2009. "We had a research team working on structural monitoring of shafts and how they performed during construction, during excavation and the effect that it had on the ground around us. We did this through a knowledge transfer partnership set up by the Technology Strategy Board," explains Mike Black. The KTP was a vehicle that enabled Crossrail and Cambridge to work together. "That was a really excellent piece of work," says Black explaining that the fibre optic sensors were installed in diaphragm wall panels. "It demonstrated that our structures were very robust, which in itself was very useful information. An incidental observation that came out of that work was the strain effects from changes in temperature."

More recent research at the University has continued along the theme of monitoring full scale tunnels and comparing the monitoring data to the results generated by centrifuge modelling and numerical analyses. "If you understand infrastructure using sensors then you are in a better position to make data-driven informed decisions whether in the long term or in the short term when you have complex construction scenarios, particularly in projects where tunnels are constructed in close proximity to existing tunnels. These sensors will give you a full picture of how the tunnel(s) is behaving and allow you to be proactive as an engineer." explains Mohammed Elshafie, lecturer at the Laing O'Rourke Centre for Construction Engineering and Technology at Cambridge University.

Elshafie points to two recent research studies on Crossrail that demonstrated the effectiveness of this approach. "In Bond St a new tunnel was being constructed right underneath the existing Royal Mail tunnel [at almost 90 degrees to it]. It was so close such that the new tunnel was touching the existing cast iron tunnel at the bottom of it. All risks were evaluated

by the design and construction teams and mitigation put into place using conservative assumptions and rightly so."

A team from Cambridge University's Centre for Smart Infrastructure and Construction (CSIC) went into the existing tunnel Royal Mail tunnel with a range of sensors from photogrammetry to fibre optic strain sensing gauges. "The level of detail and information that was extracted from these sensors during the complex construction process was unprecedented and hence, we now know a great deal about how these cast iron tunnels behave when you construct right underneath them," says Elshafie.

Using the geotechnical centrifuge the team were then able to create a small scale model back at Cambridge and simulate the effects of the construction process using cutting edge centrifuge modelling simulation techniques. The results are currently being written up by three PhD students who will submit their theses in 2017. "The main trend that we are seeing is that the existing tunnels are more resilient than we think that they are. By understanding how they behave in a real scenario and combining this with detailed studies in the centrifuge, there is the potential that the industry in general can make some significant efficiency savings either by adopting appropriate construction methods and/or providing appropriate mitigation measures when needed. In general that gives UK construction industry a competitive advantage."

Similar work was also undertaken beneath Liverpool Street but in this case the new tunnels were to run parallel to the Royal Mail tunnel. "It gave us a fantastic opportunity to look at two different scenarios. The behaviour is completely different; when it is perpendicular it is a localised effect, but when it is a parallel direction you get the effects along the entire length because you are digging beneath every single section. It was fantastic to see the difference between the two scenarios from the field data and even more fascinating to look at the models created (approximately. 1mx1mx1m) put into the centrifuge and replicate the same type of behaviour."

Future areas of research at Cambridge are considering a range of topics including the redistribution of loads around cross passages and the logistics of tunnel boring using digital modelling which will enable clients, contractors to plan the tunnelling process in a virtual environment.

Comparing lab tests with real data is also a feature of the research at Nottingham University where a key research focus is tunnel and building interaction. "What we are doing in Nottingham is we are coupling numerical modelling and centrifuge modelling in such a way that we take advantage of the strengths of each modelling technique," says Alec Marshall, associate professor at the Nottingham Centre for Geomechanics. "In a test, we replicate the effect of tunnelling on the soil and foundation system in the centrifuge and we pass information on foundation loads and displacements to a numerical model which solves for the redistribution of foundation loading based on the characteristics of the simulated building. The numerical model then passes back information about foundation loading to the centrifuge model so that the centrifuge model is continuously updated. This iterative process occurs very quickly, in near real-time, and continues until a specified level of tunnel volume loss is reached."

He says that the results are giving us a better understanding of the realistic global interactions that occur between the building and tunnel construction. "As a result of this we are developing methods which will give a design engineer more efficient and effective tools for evaluating the effect of tunnelling on piled structures."

IN THE CITY

London's City University too is undertaking research work looking at the interaction between tunnels and existing structures. A current research project looks at the effect of tunnel excavation on escalator tunnels. Another focuses on ground support at the tunnel face and the effects on stability and surface settlement. Recently published work has looked at the impact of twin tunnelling. "Up until recently it was thought that the settlement above twin tunnels would simply be superimposed on one another. We did quite a big study that showed that actually you get more movement from the second tunnel. The effect of the first tunnel has a detrimental effect on settlement above the second tunnel," explains Andrew McNamara, a senior lecturer in the civil engineering department of City University. At the same time the University has also been studying the disaggregation of slurries in pipe jacking, a project sponsored by the Pipe Jacking Association.

The PJA is also supporting a project at Portsmouth University which is studying the potential use of steel fibre reinforced concrete containing new hooked end steel fibres in jacking pipes. The objective of the project is to model the behaviour of SFRC pipes under proof loads using finite element modelling in order to develop suitable designs for various diameter pipes and to manufacture pipes according to these designs and test their performance experimentally.

SAFETY FIRST

Meanwhile at The University of Edinburgh fire safety is a key focus. For the past five years concrete spalling of precast lining segments during fire has been a major research topic, working in collaboration with consultant Arup. "When under high temperature gradients the concrete sometimes explodes away from the surface in layers, and that can be problematic for a whole host of reasons. So we are doing a lot of work at Edinburgh to try and understand that behaviour," explains Luke Bisby, Arup Chair of Fire and Structures and Head of the Institute of Infrastructure and Environment, University of Edinburgh. "What we are trying to do is understand both the physical mechanisms that influence explosive spalling and then move on to mitigation strategies or design strategies."

Fire safety expert Ricky Carvel also conducts research on tunnel fire safety at the University with his emphasis on ventilation rather than structural integrity. "I've spent two decades now looking at factors that influence fire growth in a tunnel. At the moment we are looking at the influence of ventilation on fire behaviour," he says explaining that this really consists of a complex series of interrelationships between ventilation, smoke production, smoke movement and toxicity.

A recent research paper considered the implications for a fire in the centre of a passenger train in a twin tube tunnel, similar to the Channel Tunnel. By examining the implications of ventilating the tunnel in the event of such a fire the paper made the recommendation that not using mechanical ventilation was the safer option. Carvel now wants to further the research by looking at a more generalised scenario

New leader for the Warwick MSc

This summer sees Alan Bloodworth take over from Benoit Jones who has moved to Cambridge University, as the head of the UK's only dedicated, ITA endorsed MSc in tunnelling at Warwick University. "The tunnelling industry needs more graduates and we want to attract more to the course. It has a lot of industry input and we want to get the message out," he says.

Formerly a lecturer of civil engineering at the University of Southampton, Bloodworth will bring with him his research interests which over the past five years have focussed on sprayed concrete tunnel linings. Most recently a project undertaken in collaboration with consultant Mott MacDonald has looked at the behaviour of sprayed concrete tunnels in soft ground, particularly considering the interaction between the primary and secondary linings in the presence of spray on waterproof membranes. "Now with the sprayed waterproofing membrane it bonds to both layers and so the question becomes can you take account of any bond in the first and second layers. So can we prove whether composite action happens?"

Previous assumptions for the traditional waterproof membranes that were placed rather than sprayed dictated that the primary liner became sacrificial with the inner lining taking the long term loads. However as technology moves forward so must design. "We found that you do get quite a good connection, so we have quantified that and taken the interface properties such as stiffness and put it into a finite element model of a whole tunnel and done a sensitivity analysis to support it," he explains noting that the connection has a certain amount of flexibility. "You generally get that there is sharing and composite action which leads to a sharing of load between the two layers. Primary layer actually does take a lot of the load."

Exactly how this affects tunnel design will depend on the particular tunnels and the ground supporting it, but the results will certainly impact future designs. "We are going to put out the range of interface properties that we discovered in the lab at the interface that we got and the degree of composite action that we got and then what our tunnel model then said and really what I'd like is for others to use those results in their models to find what the best combination of primary and secondary lining is. Really it is about getting that right so that you can get enough load into the secondary lining to make it worthwhile to use the composite action."

The next step for the research is to undertake the tests with a saturated lining and if possible undertake in situ experiments on an existing tunnel.

Above: The Royal Mail Tunnel

NO DIG LIVE

The UK-based trenchless technology show returns to the popular new Peterborough venue

FOLLOWING THE SUCCESS of the previous No-Dig Live held in September 2014, the 13th biennial trenchless technology exhibition, outdoor demonstrations and seminars will return to Peterborough Arena, 20-22 September 2016.

The recent event featured more than 100 companies, both from home and overseas, presenting an impressive range of products and services for undertaking projects using trenchless technology.

The facilities at the new venue brought the outdoor demonstration area much closer to the indoor exhibits – a feature verbally appreciated by exhibitors and visitors alike. The warm autumn sunshine was a contributing factor to this success, as the huge cargo doors were left fully open during the show, ensuring a free flow of visitor traffic between the two areas.

Visitors to the show were offered a wide-ranging programme of educational opportunities.

A visit to the exhibition and demonstration area is an unrivalled forum to see the latest innovations, to see equipment in a live working environment and to discuss how products can enhance the visitor's business

When and where

Dates: 20-22 September 2016
Venue: Peterborough Arena, East of England Showground, Peterborough PE2 6XE

Links

www.nodiglive.co.uk
www.ukstt.org.uk

Table 1. Exhibitors list

Company	Stand Number
3M	Outdoor 1
ASHTEAD TECHNOLOGY	Indoor 55
BREWIS ENGINEERING LTD	Indoor 99
BUCKHURST PLANT HIRE LTD	Indoor 19
C J KELLY ASSOCIATES	Indoor 71/115
CATSURVEYS GROUP	Indoor 95
C-SCOPE INTERNATIONAL LTD	Indoor 111
DCR INSPECTION SYSTEMS LTD	Indoor 87
DITCH WITCH UK	Outdoor 11
DRAIN TRADER	Indoor 7
DRAINCARE LTD	Outdoor 28
E C HOPKINS LTD	Outdoor 27
ENVIRONMENTAL TECHNIQUES	Indoor 35
ER TECHINICAL SERVICES	Indoor 101
FLUVIUS GMBH	Indoor 127
FUTURE WATER ASSOCIATION	Indoor 43
GEORGE FISCHER SALES LTD	Indoor 93
HERMES TECHNOLOGIE LTD	Indoor 135
I. S. T. INNOVATIVE SEWER TECHNOLOGIES GMBH	Indoor 3
IPEK INTERNATIONAL GMBH	Indoor 73/15
JET AIRE (DC) LIMITED	Outdoor 25
JETCHEM SYSTEMS LTD	Outdoor 19
KERNEOS LIMITED	Indoor 9
KILBRIDE ENVIRONMENTAL SERVICES	Indoor 13
LANGFANG ORIENT PETROLEUM MACHINERY CO.,LTD	Indoor 37
MAMMOTH EQUIPMENT	Outdoor 31
MARPLAST SP.ZO.O	Indoor 1
MBW EUROPE LTD	Indoor 123
MCALLISTER BROS LTD	Indoor 105
MINI-CAM LTD	Indoor 125
MTS PERFORATOR GMBH	Indoor 103
NAYLOR DRAINAGE LTD	Indoor 117
NORDITUBE TECHNOLOGIES SE + RTI ROHRTECHNIK INTERNATIONAL GMBH	Indoor 91
NORMAG B.V	Indoor 67
ONSITE	Indoor 129
PICOTE UK LTD	Indoor 69
PIPE EQUIPMENT SPECIALISTS LTD	Indoor 119
PIPELINE INDUSTRIES GUILD	Indoor 47
PLANNED MAINTENANCE (PENNINE) LTD	Indoor 63 / Outdoor 18
PROKASRO MECHATRONIK GMBH	Outdoor 3
PSS HIRE	Outdoor 7
RADIODETECTION LTD	Indoor 137
RAEDLINGER PRIMUS LINE GMBH	Indoor 97
RELINEEUROPE AG	Indoor 75/113
RESCHWITZER SAUGBAGGER PRODUKTIONS GMBH	Outdoor 6
RIDGE TOOL UK	Indoor 89
RITELITE SYSTEMS	Outdoor 65
RSM LINING SUPPLIES GLOBAL LTD	Outdoor 9
SAERTEX MULTICOM GMBH	Indoor 85
SANEXEN ENVIRONMENTAL SERVICES INC	Indoor 25
SCANPROBE TECHNIQUES LTD	Indoor 27
SOURCE ONE ENVIRONMENTAL	Outdoor 59
STEVE VICK INTERNATIONAL LTD	Outdoor 55
SYNTHOTECH SPECIAL PRODUCTS LTD	Indoor 11
T A DRILLING (SALES) LTD	Outdoor 33
TRENCHLESS SOLUTIONS	Outdoor 61
TT GROUP	Outdoor 5
UKSTT	Inside 109
UNDERGROUND UTILITIES	Indoor 45
VIP POLYMERS LTD	Indoor 83
VISSER & SMIT HANAB BV	Indoor 81
VIVAX-METROTECH LTD	Indoor 5
VPPLC	Indoor 107
WET NEWS	Indoor 33
WARDSFLEX	Indoor 21
WINCAN EUROPE	Indoor 53

TEST OF STRENGTH

Rhian Owen
Rhian began working with *Tunnels and Tunnelling* in 2011

The redevelopment of Bond Street Tube station has recently trialled a new method of early strength monitoring of shotcrete. **Rhian Owen** highlights the risks of spraying concrete and how Strength Monitoring Using Thermal Imaging (SMUTI) could help eliminate the dangers

A WORKER WAS CRUSHED TO DEATH by falling shotcrete on 7 March 2014, 10m into a tunnel in Holborn, Central London. Rene Tkacik, 44, was carrying out SCL works during construction of a crossover cavern between the two main western running tunnels in Holborn for Crossrail, when nearly a tonne of concrete from the crown fell on him.

An inquest was heard in February last year, which revealed that Tkacik, a Slovakian national, was an experienced construction worker. However, the jury ruled his death had accidental contributory factors including him not being able to understand all briefings. No one faced prosecution for the death.

In the wake of the accident, the risks of spraying concrete were brought to the public's attention with contactors keen to try safer methods that will protect site workers from the dangers of sprayed concrete lining failures.

TRADITIONAL METHODS

Shotcrete lining forms an integral part of conventional tunnelling and is widely applied for underground excavations. Shotcrete gains strength in a similar way as ordinary concrete gains strength, with the classic S-shaped curve.

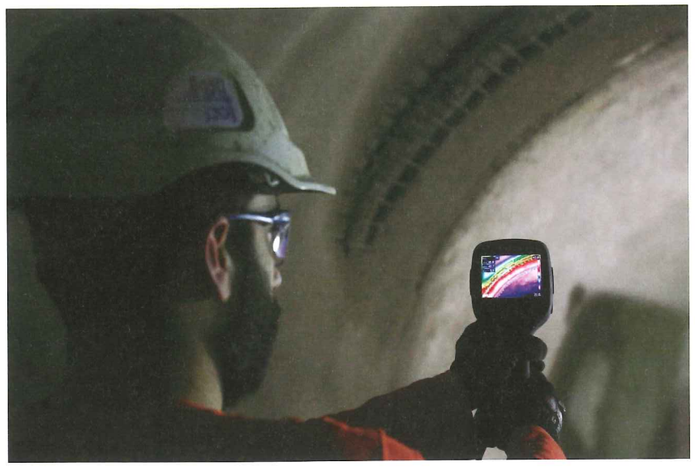
Engineer using SMUTI to monitor lining strength

Strength monitoring of shotcrete is vital; important for two key reasons. The first is re-entry time: this is based on measuring the developing strength of shotcrete until an adequate strength value is reached. The second reason is that shotcrete linings are loaded at early age as the tunnel advances, and it is important that the shotcrete gains strength at a rate corresponding to the rate of loading, so that safety is maintained at all times and the lining is not overstressed.

Strength monitoring is traditionally performed by needle penetrator and Hilti nail guns, followed by testing of cylinders cored from the lining or from a panel sprayed at the same time as the lining.

The main drawback with these methods are that they are local, destructive, some produce waste - unused Hilti nail gun cartridges are classified as hazardous waste - and they also introduce additional risks. Furthermore, checking the early strength of the shotcrete in the crown is particularly difficult; a scaffold or a MEWP is needed.

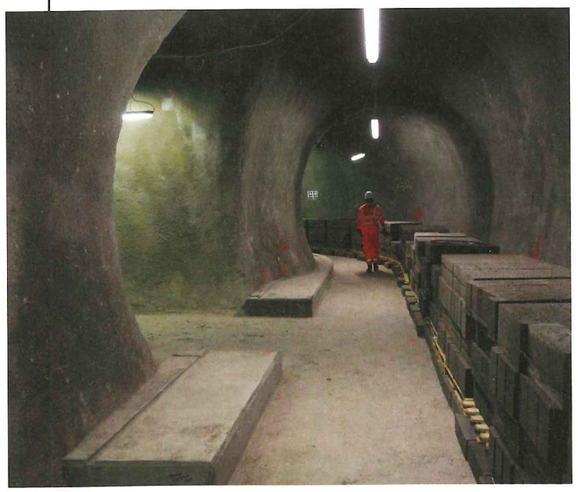
"The issue with the needle penetrator and the Hilti nail guns is that you have to get right up to the piece of concrete you're testing; somebody has to go there physically and push a needle into it or fire a nail into it," says Aled Davies, Senior Tunnel Engineer, Costain. "Therefore, potentially if you're digging a tunnel, the shotcrete that is of most concern is right up next to the tunnel face. That's not somewhere you want to be standing, so you've got to rely on test panels and you're hoping that the tiny little area you're testing on the test panel is representative of 10m³ of shotcrete."



Above: Engineer using SMUTI to monitor lining strength

Below, left: A section of SCL tunnels prior the start of block-laying to support tiling

Above, right: Secondary lining spraying underway to a tunnel which extends an existing escalator lower machine chamber and concourse



The development of Strength Monitoring Using Thermal Imaging (SMUTI) was driven by dissatisfaction of current strength tests for monitoring sprayed concrete. SMUTI is a patent-protected invention created by Benoit Jones from the University of Cambridge also, also inventor of SMUTI and Director of Inbye Engineering.

The approach is based on developing temperature histories for the shotcrete lining using onsite thermal imaging. Knowing this temperature history enables the engineers to calculate the amount of hydration that has taken place in the concrete, and hence its strength.

For the last 25 years the Arrhenius function has been used. It can be said that for a given concrete mix, the rate of hydration at any time is dependent on only the temperature at that time and the degree of hydration that has already occurred.

In order to use the Arrhenius equation the normalised affinity needs to be known, as well as the activation energy and the temperature.

"First, we need to do some laboratory tests and work out a couple of thermodynamic parameters for the cement and mixtures that are being used. We then do some calibration on site with some sprayed panels to work out the relationship between the amount of chemical reactions that have taken place and the strength, and then we input all of those parameters into the software," explains Jones.

"So when we are spraying the concrete, and afterwards, we can use a thermal imaging camera to measure the temperature of the shotcrete, and put that data of times and temperatures since we've sprayed it into the software and it tells us what the strength is. It allows us from a remote and safe position to check the whole sprayed concrete lining.

"It's a very straightforward procedure, it's as easy as taking a photo."

Since SMUTI allows workers to directly monitor the compressive strength development of sprayed concrete while remaining at a safe distance, it provides a vast improvement on traditional tests that are local and rely upon a small test panel, which may not be representative since the panel and the lining may have a very different temperature history due to the different size, time of spraying and environmental conditions. This is a step-change in safety and quality control of shotcrete tunnelling.

"When performing a local test on a panel, it's basically assumed that the whole lining is behaving in the same way as the panel, but the SMUTI method gives you much more assurance that the whole lining is doing what it is expected to be doing. It could also flag up issues that you wouldn't know otherwise," says Jones.

Above: A new SCL tunnel proving access to the Jubilee Line platform

Below: Secondary lining spraying underway in Shaft 3, the final section of sprayed concrete lining on BSSU

THE TRIAL BEGINS

A Costain and Laing O'Rourke joint venture, with technical support by London Bridge Associates, has recently trialled SMUTI to test the strength of sprayed concrete at its Bond Street Station Upgrade (BSSU) project, on behalf of London Underground. The project is the first in the world to test the new technique in a production environment.

The BSSU project is a GBP 302M, seven-year project which will open in 2017. Bond Street Tube station is one of the busiest stations on the Underground network; there are over 173,000 passengers that use the station every day and numbers will increase to over 225,000 when Crossrail arrives in 2019.

Bond Street is set to benefit from a

number of improvements, including: a new entrance on Marylebone Lane, on the north side of Oxford Street; new escalators serving the Jubilee line; lifts to provide step-free access from street to all platforms; 30 per cent more capacity, plus more passageways to reduce journey times; and improved interchange between the Central and Jubilee lines.

Earlier this year, following extensive laboratory testing, production trials began on-site at BSSU. First, the concrete in 12 sprayed concrete panels was tested simultaneously using the established in-situ tests and SMUTI. This provided sufficient data to carry out trials in a production environment and in March, BSSU implemented the SMUTI system alongside existing test methods for the first time.

"We were already concerned that we could do more as an industry to make the sprayed concrete process even safer and it just so happens that SMUTI came at the right time for us," says Davies. "We were carrying out sprayed concrete work at Bond Street when Benoit Jones was available to come and demonstrate the technology."

Jones adds: "From my point of view, I was invited to come and talk to the guys on the site here and we had several conversations early on with the whole site team - Costain Laing O'Rourke and London Underground.

"It was important to me to be able to work with people who understand how technology needs to be developed through using it.

"In a sense this is what we could call a Beta trial; before this job started we knew SMUTI could work, but we needed to test the reliability and how easy it is for the shift engineers on site to actually do it and input the data into the software.

"To work with people who understand that and who work with you to help improve the system, well that was a big attraction for me."

In order to develop and improve the method, Jones says that on site trials and research are vital. The BSSU project also highlighted areas that need further development. "There's definitely work needed to improve the software interface.

Currently reports are generated as a PDF, so it will be beneficial to also be able to download to excel or data files, that you can then manipulate the data better in excel or other spreadsheet packages.

So there are things that we can develop from now on. In terms of the reliability of the data we are still in the process of churning the numbers on that"

*Top: **Engineers carrying out checks prior to the construction of a secondary lining invert slab in a tunnel***

*Above: **View into Conc1 during construction of the escalator barrel to the right***

TUNNEL WARFARE

This article is the second part of an insight into wartime tunneling by **Myles O'Reilly**. The first part can be found in the previous issue of *Tunnels and Tunnelling* (July 2016, pp.45-50)

THE MAIN BRITISH mining operation of 1915 was that at Hill 60 and has already been described. Other than this, no great effort was made to coordinate the mining operations with any military initiative; even the mines detonated at the onset of the Battle of the Somme in mid-1916 had little impact on the outcome of the ensuing prolonged bloodbath. Mining remained localised and consisted of recurring episodes of tit-for-tat mining and counter mining with the British as they gained in experience and organisation slowly nullifying the initial German advantage.

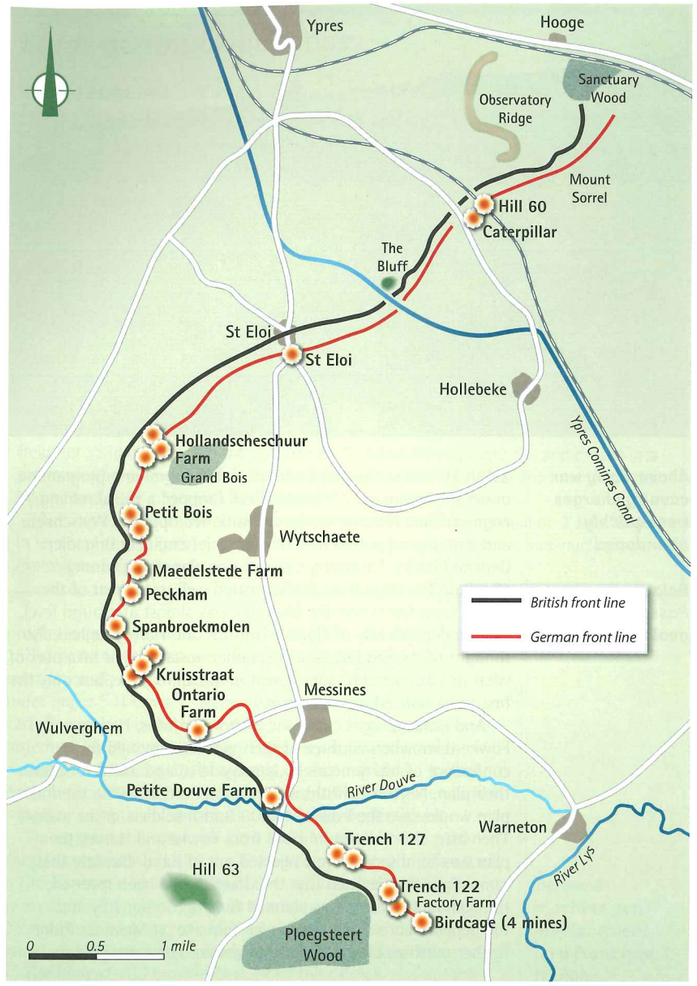
Artillery emplacement on the Western Front

At the end of 1915 some 20 tunnelling companies each comprising up to 1,000 men and ever increasing quantities of equipment had been formed. Losses were high; almost 1,000 men were killed, wounded or ill each month and had to be replaced. In addition, apart from tangled networks of galleries around the trenches, some enemy casualties and shaken German morale, there was little to show for this considerable effort.

However, improvements were on the way. On 1 January 1916 Brigadier General R N Harvey was appointed inspector of mines with overall control over the tunnelling companies and the integration of their work into the war effort at as a strategic as well as a tactical level. It all culminated in the greatest feat in destructive military mining the world had ever witnessed at Messines Ridge on 7 July 1917 as the prelude to the successful assault there.

THE YPRES SALIENT

The geology of the Messines Ridge is straightforward, a succession of horizontal clay and sand layers of the Paniselian Formation overlying the Ypres clay that forms much of the Flanders plain. The ridge has a covering of Quaternary sand that reaches a thickness of some 30m to the south of Kruisstraat.



Above: Ypres Salient map showing the two lines of trenches

The struggle here was determined by topography and geology. The Germans held the advantage above ground overlooking the British positions to their west from the high ground of the Messines Ridge. A north-trending spur of the main Passchendaele Ridge. On the other hand the British had easier access to the Ypres blue clay and the sandy clay and the clay layers of the Paniselian Formation on top of it. Like its London clay counterpart the Ypres blue clay is stiff, overconsolidated and prone to swell when exposed to moisture; it is eminently suitable for tunnelling. Above those lie the Kemmel Sands which were an almost impassable obstacle to mining. Up to 10m thick along the Ridge this layer of fine sands was full of water trapped between the moist or dry clays below and a seam of moist sandy clays above; the result was a layer of quicksand aptly known to the German miners as 'schwimmsand', meaning swimming sand. All attempts to drive tunnels at depth beneath the Ridge were bound to intercept this saturated layer unless their entrances were located in the low ground to the west behind the British lines or in the valley of the River Douve.

The impasse of the Kemmel Sands was overcome in May 1915 at Cuinchy where a 1.8m diameter spiled timber shaft was sunk through 2m of running sand into the dry clay underneath by a section of 170 TC under Lieutenant J A Leeming. He was immediately instructed by Major Norton-Griffiths to seal the shaft with a cylindrical iron lining; a supply of specially designed steel tubbing, initially fabricated in France and later in Britain was obtained. Such steel linings, typically 1.8m in diameter, were to become the key to shaft sinking through the waterlogged sand layers into the stiffer and drier clays underneath. They were easy, quick and safe to install; if great thickness of saturated sand had to be penetrated two or three diameters

Historical note

Hitler, apart from leave, hospitalisation and convalescence, spent from late 1914 to 1918 on the Western Front for the most part attached as a dispatch runner with the rank of Gefreiter to the headquarters of the 16th Bavarian Reserve Regiment; his decorations included two Iron Crosses. Among the places where he served were Gheluvelt, Wytschaete, Messines, Comines, Fournes, Fromelles, Vimy and the Somme. It is inconceivable that he would not have been well aware of the war underground.

of tubbing could be used with the size of the shaft decreasing with depth. As soon as the tubbing was embedded in the clays the shaft was continued with timbering.

When the required depth had been achieved tunnelling began with galleries being driven towards the enemy positions by the clay-kickers. Again, support was crucial to maintain stability. Invariably tunnels in clay in Flanders were close timbered. This involved the construction of a continuous enclosure of wooden boarding supporting the roof, sides and floor inside which the miners worked. The tunnel was advanced in nine to 12 inch (230 – 300mm) increments by carefully and as silently as possible excavating the ground ahead to the exact shape so that the next timber sett could be inserted. Nine by three inch (225 by 75mm) hardwood planks for strength and durability with stepped joints were commonly used as support. By the middle of 1916 the British had standardised the internal dimensions of their workings; ordinary offensive and defensive tunnels were 1.3m by 0.69m increasing to 1.5m by 0.76m near the shaft bottom while communication tunnels were 1.83m by 0.9m.

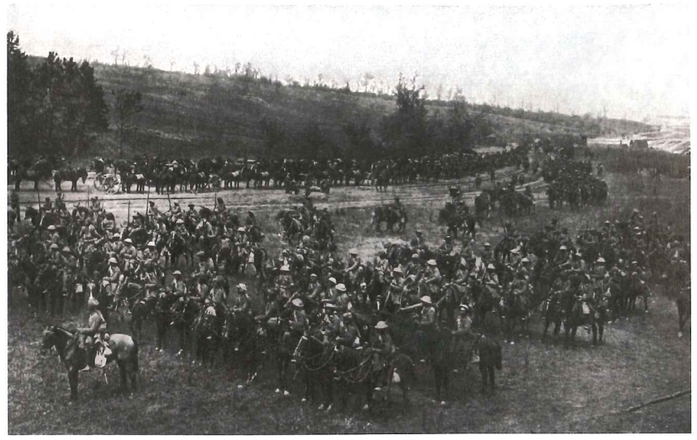
These dimensions were chosen to maximise progress but were certainly cramped. Infantry detailed to assist the miners particularly disliked that chore. Conditions were uncomfortable, dim and generally stuffy; water often dribbled into shallow tunnels. Although rarely encountered there could be problems with ventilation and with lack of oxygen and with the increased pressures on the timber support in the deeper tunnels. But above all this, the perpetual game of cat and mouse, kill or be killed, pervaded the atmosphere. It was psychologically disturbing and nerve-wracking for the tunnellers, officers and men; and only alleviated by liberal supplies of rum.

THE BIG IDEA

The Big Idea was sown in Norton-Griffiths' mind in spring 1915 as he stood in the rain gazing across no-man's-land at the German front line along the Ypres Salient with Wytschaete and Messiness further behind. Mulling it over and examining trench maps he became convinced that six large deep mines placed strategically should be capable of blowing the Germans off the Messines Ridge. He sent the idea to Colonel R N Harvey but it was reject out of hand by Brigadier General Fowke, engineer-in-chief. But Harvey was persistent and ultimately won Fowke around to the idea.

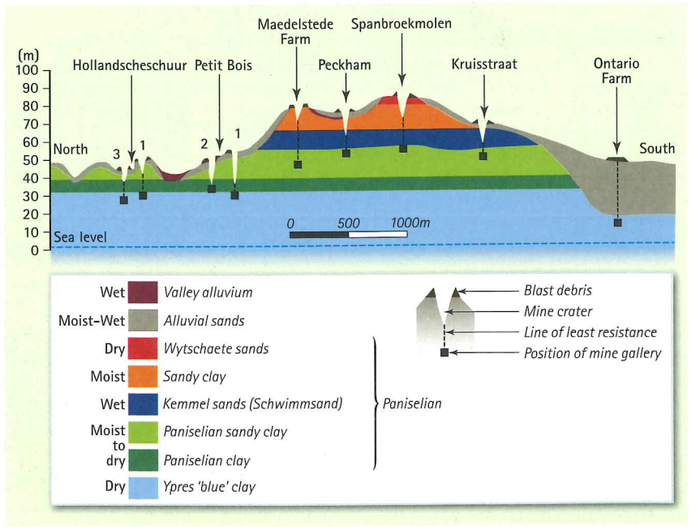
In November 1915 newly formed 250th TC was settling down to an ambitious mining programme under the command of Captain Cecil Cropper, a metal mining engineer from Northumberland. Positioned opposite Wytschaete and strongly supported by Canadian chief engineer Brigadier General Charles Armstrong Cropper was planning a tunnel attack on the ridge from shafts located well to the rear of the British front line where the blue clay was almost at ground level. Quite independently of Norton-Griffiths and Harvey he had also thought of the Big Idea and was rather upset at their take over of what he considered his idea. Great minds think alike, but only the first to be noticed gets the prize.

And luck was again with the Norton-Griffiths, Harvey and Fowke team when all three of them were summoned to a conference of top generals in January 1916 and asked to submit their plan. Norton-Griffiths did the presentation telling them the plan would save the lives of 10,000 British soldiers in the assault Then after shorter contributions from Fowke and Harvey the plan was for a second time rejected out of hand. But late that same night they learned that the decision had been reversed; the Somme Offensive was planned for the coming July and the generals considered that an 'earthquake' at Messines Ridge further north would be an ideal diversion. There was just six



*Above: **Early war cavalry charges were quickly abandoned***

*Below: **Passchendaele geological profile***



Large non-nuclear bangs

Planned explosions

The explosion of 19 mines charged with 417 tonnes of explosives mainly ammonal on 17 June 1917 at Messines was almost certainly the largest planned in history until the 1945 atomic bomb test in Nevada USA. The destruction two years later of German fortifications on the North Sea Island of Heligoland involving some 4,000 tonnes of surplus Second World War ammunition easily surpassed the events at Messines. According to the project officers report 'Minor scale event' by the Defence Nuclear Agency at Kirkland Airforce Base, the largest known non-nuclear explosion was carried out at White Sands Missile Range in New Mexico on 27 June 1985; it involved the detonation of about 43,000 tonnes of ANFO to simulate the effects of nuclear weapons on military vehicles.

Accidental explosions

The largest bang of manmade explosives during the First World War was at Halifax, Canada, on 6 December 1917, when the SS Mont Blanc, a French cargo ship carrying about 2,600 tonnes of assorted wartime explosives, collided with the Norwegian freighter SS Imo. Following the collision the SS Mont Blanc caught fire and drifted into the town where it exploded. Some two thousand people were killed and nine thousand injured and much of Halifax was destroyed.

The explosion of an N1 rocket in the Soviet Union on it launch pad on 3 July 1969, in terms of energy release, is considered to be the largest man made non-nuclear explosion of all time.

months to get it all ready.

But parts of the plan were already being implemented unintentionally by Cropper as outlined above and by 175 TC under major S H Cowan, already blooded at Hooge, who had started work late in August 1915 on a two-pronged gallery targeting Hill 60 and Caterpillar. Here they had succeeded in reaching the blue clay by laboriously driving a timbered incline through the unstable overlying saturated strata. The gallery driven from it at a depth of 28m was known as the Berlin tunnel.

Throughout the spring of 1916 Field Marshall Sir Douglas Haig, Commander in Chief, continued to plan for a double attack in the summer - an initial attack through Flanders to be followed by an Anglo-French offensive at the Somme. So the tunnelling effort continued along the Messines Ridge where orders were issued mid-February to be ready for action by mid-June.

The longest and most important of the tunnels was at Petit Bois and was least likely to meet the deadline if clay-kicking was used. In an effort to speed up progress instructions were issued to press the excavation well ahead of the timbering; progress rates shot up only for disaster to strike after three days when 13m of tunnel collapsed and the new method had to be abandoned. Simultaneously, Norton-Griffiths was involved in the procurement of a 2.4m diameter tunnelling machine, the Stanley Heading Machine manufactured in

Nuneaton and originally designed for use in coal mines. After many misadventures in transit and during assembly on site this machine commenced boring on 4 March. It advanced at about 0.6m per hour for several hours; however, when the machine was stopped it stuck fast in the swelling clay and had to be dug free. The problems multiplied; the electric motor driving the compressor failed; it repeatedly became stuck and had to be freed; the machine tended to dive. By the time the machine had laboriously dug about 60m of tunnel enough was enough and the machine was abandoned and never retrieved.

At Hill 60 the Berlin Tunnel was in a poor state as result of the combined effects of seeping water and nearby mining, shelling and trenching. When early in April the third Canadian TC took over from 175 TC, their inheritance included some 60m of collapse tunnel the result of a recent camouflet that had forestalled and eliminated German countermining in the vicinity. Despite the shattered ground and the mangled timbering the collapsed section was quickly recovered.

Some 5km along the frontline to the right the Hollandscheschuur Farm Tunnel had been driven 240m across no-man's-land by early June despite persistent flooding and counter mining as well as accurate mortar fire from the Germans. At Peckham to the south ground pressures were very high; support which had been adequate in other tunnels snapped and had to be replaced with 175mm balks of wood.

But at Petit Bois the supposed Achilles Heel of the plan where both a new tunnelling technique and a tunnelling machine had failed men of 250 TC had kicked their way for 485m to the point where the tunnel branched to allow two mines to be placed. Some 13 tunnellers were down at that junction early on the morning of 10 June 1916 when the Germans detonated two charges, collapsing a length of tunnel and entombing the men. The rescuers found the tunnel blocked at about

*Below: **A machine gun emplacement on a front line trench***

380m and although chances of survival were considered poor Cropper ordered an all-out rescue attempt. Rather than try to clear the 100m or so of mangled debris it was decided to drive a bypass tunnel alongside; spurred by the plight of their trapped comrades the rescuers tunnelled with incredible energy averaging over 12m advances per day compared with 4.5m normally. Finally they broke through after six and a half days to find that only the doughty sapper William Bedson was still alive; all his companions had indeed survived the blast but had died before help could reach them. Work on the tunnel was immediately restarted and advanced to 548m where it once again branched right and left into shortish galleries, some 79m and 64m long respectively, and two heavy charges were subsequently placed.

But by now mid-June 1916 was upon them. Most progress had been made along the southernmost 5.5km where 171 TC had laid five mines. One of 30,000lb (13,608kg) of ammonial was in a tunnel that had started in Ploegsteert Wood and had been charged and wired in February. Similarly two mines had been placed in a tunnel from Trench 127; one of 36,000 (16,330kg) ammonal on 20 April and the second larger charge of 50,000 (22,680kg) ammonal less than three weeks later. Then in mid-May and June two further charges had been placed in the forked tunnel starting from Tench 122. Some of the great and good seemed to be in on this act as Winston Churchill was in charge of a batallion of the 6th Royal Scots Fusiliers stationed in Ploegsteert Wood during the opening four months of 1916 following his resignation the previous November as First Lord of the Admiralty after the Gallipoli debacle.

Finally 171 TC was preparing the sixth mine at Spanbroeknolen with massive charge of 91,000 (41,278kg) ammonal packed in 1,820 sealed tins each weighing 50lbs (23kg). The charging, wiring and tamping were all completed by 25 June 1916 but still there was no news on the Flanders attack date. With French forces being inexorably sucked into the bloodbath at Verdun the campaign at the Somme became a mainly British undertaking. An attack at Messines would have to wait.

With both sides so heavily engaged to the south there was time to complete the tunnels already underway at the end of June 1916. Five were ready charged, wired and tamped - one each at Hollandscheschuur, Petit Bois and Peckham with a pair at Kruisstraat. A further four were added in August at Hill 60, Hollandschuur, Petit Bois and Kruisstraat. Finally a mine was placed at Caterpillar in October 1916 and at Kruisstraat in April 1917 to complete these tunnels. New tunnels were started at St Eloi in August 1916 and at Maedelstede Farm in September to complete the mines that would be blown in the attack on Messines Ridge.

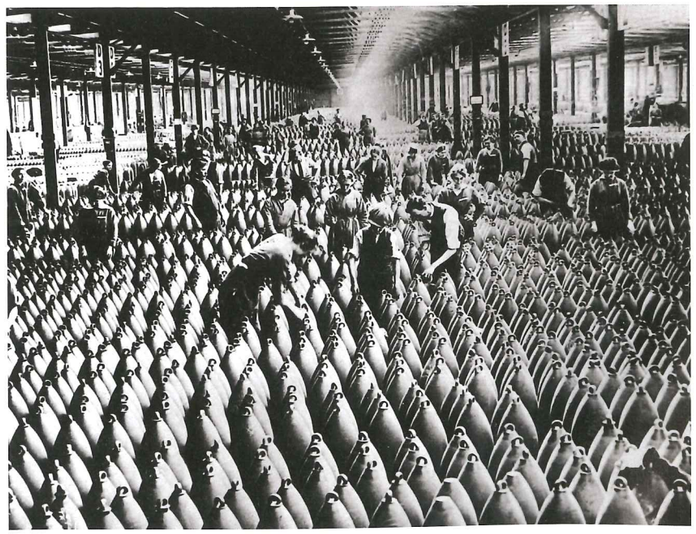
There were two major problems which made this approach problematic. The mines would be in the ground for many months - over a year as it turned out in some instances - exposed to the risk of discovery and countermining by the Germans and to deterioration of the explosives and wiring due to moisture. Ammonal, the main explosive used, was highly absorbent and unreliable when its moisture content exceeded four per cent, so the effectiveness of the sealed tins in which it was supplied was crucial.

The suspense was soon increased at Petit Douve Farm on 24 August 1916 when a spur tunnel off a deep gallery beneath the farm drove unexpectedly into a German tunnel. As the collision could not be concealed an exchange of camouflets ensued which resulted in the abandonment of the gallery and the charge already placed in it.

In mid-February 1917 the last of the succession of German camouflets at Spanbroekmolen did extensive damage; the wiring had completely failed and 120m of tunnel was beyond repair. Work was begun by 171 TC to drive a bypass alongside and although there were grave misgivings whether the new tunnel would be completed in time it made it with less than a day to spare. Indeed the end was nigh. At the meeting between the British Commander-in-Chief Douglas Haig and General Herbert Plumer commander in the forces in the Ypres Salient on 7 May it was agreed that an attack on Messines Ridge would take place in a month's time on 7 June 1917. The opening gambit at zero hour was to be the firing of 19 mines along the 16km front. But there were still some doubts even at this late stage; three mines were still being excavated or charged and the one at Spanbroekmolen had to be repaired.

The northern most mines consisted of 53,500lb (24,268kg) mixture of ammonal and gun cotton and 70,000lb (31,8075kg) ammonal under Hill 60 and Caterpillar spoil heaps respectively. Both had been laid from the Berlin Tunnel from autumn of 1916 by the third Canadian TC, which had been relieved by the first Australian TC in November. The latter had sunk a steel shaft to replace the seriously leaking and fragile incline there and were

Below: ***Shelling was expensive and deadly but not always effective at destroying deep fortifications***



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being constantly harassed by the enemy both below and above ground. With only three days to go the Germans were detected advancing towards the charges but at a rate, even if their tunnel drive was accurate, too slow to find them before zero hour.

At St Eloi just over 3km to the southwest was the largest charge of the war, a massive 95,600lbs (43,364kg) of ammonal laid at a depth of 38m by 1st Canadian TC. Work on the 503m tunnel had started mid-August 1916 and charging was completed on 28 May 1917 with just nine days to spare.

Southwards from St Eloi came the seven mines laid by 250 TC. First a cluster of three mines laid in branches from a single tunnel at Hollandscheschuur completed in June, July and August 1916. Then 900m or so to their right were twin mines each of 30,000lbs (13,608kg) of ammonal and blastine, one at the end of the 631m tunnel, the other in a 64m branch from it at Petit Bois - the scene of the Sapper Benson ordeal and the abortive efforts to tunnel through the clay by the Stanley Heading machine. Next came Maedelstede Farm where 94,000lbs (42,638kg) mostly ammonal was completed on 2 June a mere four days before zero hour. And lastly at Peckham Farm where the drive had been plagued with inflows of water, mud and saturated sand and swelling ground; then in January 1917 a section of tunnel collapsed and a 20,000lbs (4,072kg) mine was irretrievably lost; a bypass tunnel was driven and the wiring to the 87,000lbs (39,463kg) charge reinstated.

Nearby, at Spanbroekmolen the situation was fraught to the bitter end. As already described a 91,000lbs (41,278kg) ammonal charge had been laid in June 1916 by 171 TC and all remained quiet until February 1917. Then the driving of a branch tunnel to place a second mine alerted the Germans to the situation and their retaliatory series of camouflets ruptured the leads to the mine already in place. Again a bypass tunnel had to be driven to recover the situation a priming charge of dynamite being placed hard against the ammonal with just hours to spare.

Proceeding southwards the threesome of mines at Kruisstraat came next and the longest, 658m, tunnel of them all. Again the work of 171 TC, these mines one of 49,500lb (22,453kg) and two each of 30,000 (13,608kg) mainly of ammonal were located to neutralise the German front, support and reserve trench lines. The 60,000lb (27,216kg) ammonal mine at Ontario Farm followed. Here again there was a desperate race against time but once more 171 Tunnelling Company won and accomplished their task with only a few hours in hand.

The last four mines to the south of Ontario farm had all been placed between late April and mid June 1916 and had laid there undisturbed for over a year. However on 4 June 1917 a stray shell damaged a 21m deep shaft carrying the leads from the pair of mines at Trench 122, necessitating rewiring; the repairs were completed by Lieutenant Cecil Hall of 3rd Canadian TC with just 20 minutes to spare. All was now ready for the big blow, the culmination of Norton-Griffiths' Big Idea. More than 100,000 troops were massed for the assault at zero hour, 03.10 hours, on 17 June 1917. At about 03.30 hours the mine at Peckham Farm was detonated; Spanbroekmolen was fired 20 seconds later with, Kruisstraat two seconds behind and so on. All 19 mines charged with a total of 933,200lb (423,300kg) explosives had been blown virtually simultaneously, a magnificent achievement for the tunnellers.

The Battle of Messines was now on. By 07.00hrs the villages of Messines and Wytschaete were captured and by midday the fighting had moved well beyond the ridge crest towards the final objectives. The demoralising effects of the mines on the defenders had been overwhelming. German soldiers were seen staggering about, weeping, scrabbling on hands and knees and utterly confused. The attackers had expected stiff resistance but much of the advance was virtually unopposed. Total German casualties are not known, but 10 officers and 679 men died at Hill 60 and Caterpillar alone; a further 400 were obliterated by the St Eloi blast. Extrapolations from these examples are problematic since these sectors were heavily manned. Elsewhere trenches were often lightly manned. Further to the south, opposite Trench 121 and just outside the scope of the assault the local German commander had ordered a limited withdrawal, which would have completely negated the effects of mining.

CONCLUSION

The capture of Messines Ridge was a key episode in the First World War; the swift victory was a spectacular triumph stemming from the nerve-racking, painstaking and courageous efforts of the tunnellers over the one and a half years. But it was also the end of large scale mining warfare by the armies of the major powers. However, tunnels can still play a crucial role when the geology is favourable as the Viet Cong showed with their Cu Chi tunnel system in the Vietnam conflict

BIG CITY MOVE

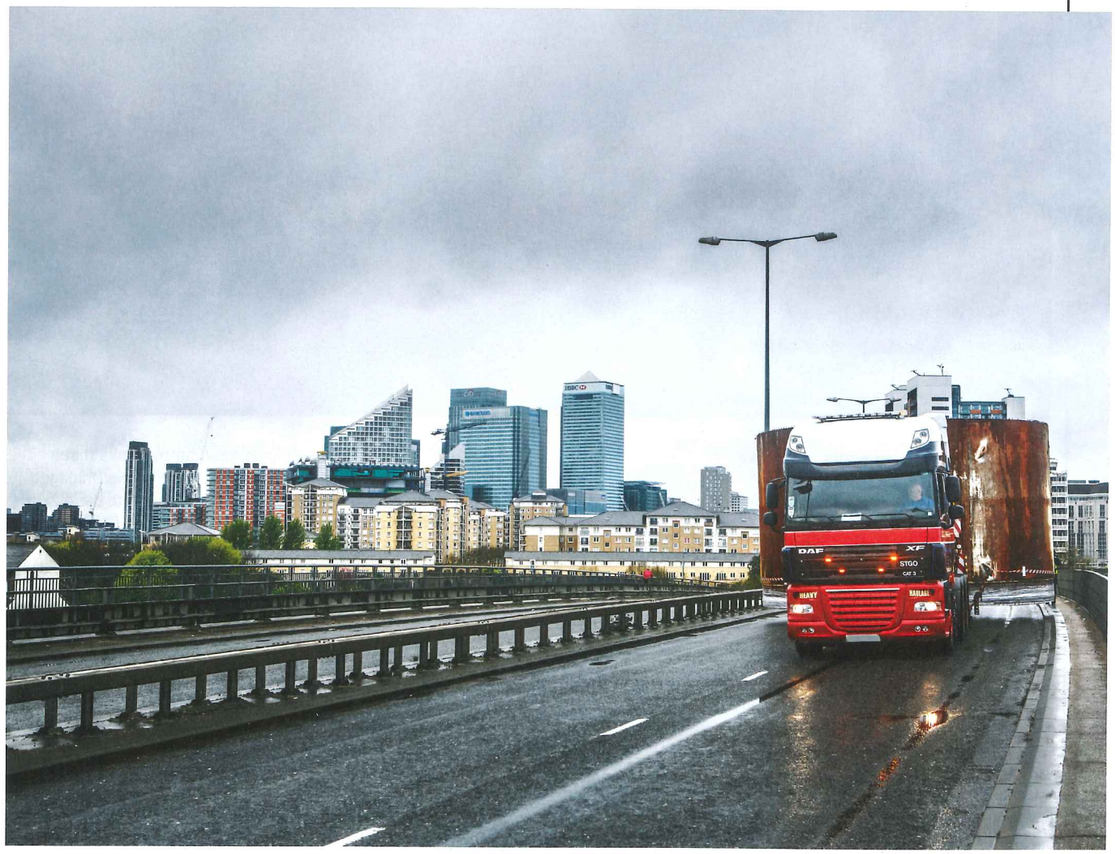
TBMs are being built on an ever larger scale, pushing the limits our congested cities can accommate. **Rhian Owen** speaks with two freight forwarding companies about the obstacles they face when machines through large cities

Rhian Owen
Rhian began writing for *Tunnels and Tunnelling* in 2011

LAST YEAR, THE ECONOMIST REPORTED that one in three railway bridges in Germany is over 100 years old. The report added that in the US the average bridge is 42 years old and the average dam 52. Although America's infrastructure has not been considered a national priority for many years, the report from the American Society of Civil Engineers highlighted the urgency, with 14,000 of the US' dams rated as 'high hazard' and 151,238 of its bridges as 'deficient'. Crumbling infrastructure is not only dangerous, but can debilitate a TBM move through a city.

Concerns about the infrastructure market have been triggered by tragic failures of existing infrastructure - such as the collapse of the 40-year-old I-35W Mississippi River bridge, which 13 people and injured 145. There is also concern about the kind of projects we're building today. Alaska's proposed 'Bridge to Nowhere', which would have connected the small city of Ketchikan to its airport on nearby Gravina island, became a symbol of wasteful US federal spending, and was scrapped late last year.

"It's getting tougher and tougher in the marketplace," says Jon Eaton of Wallenius Wilhelmsen Logistics Abnormal Load Services (WWL ALS). "There's not a lot of investment going into the infrastructure, a lot of bridges that you could once go over with a certain tonnage are now being reduced in tolerance levels. It means



having to find different routes, which may mean more street furniture has to come out or a longer way around it. Or putting more axles onto the trailers, because the bridge teams will tell us we need to be at 11t per axle and we then have to add or subtract axles to meet that level. For example, we had a route signed off, twice in fact, for a TBM going from one of the Crossrail sites back into Germany. But then the machine got delayed in the tunnel and by the time we reapplied to use this route one of the structures got downgraded, which meant that all the work we put in to find the route went out the window. We had to find another route. That's one of the problem we face at the moment, investment in the actual infrastructures."

Today's TBMs are getting bigger, pushing the limits that a city can accommodate. A 17.6m diameter machine by the Dragages/Bouygues JV for its design-build contract to excavate the 4.2km long undersea Tuen Mun - Chek Lap Kok Link (TM-CLK) highway project in Hong Kong, is now the world's largest TBM. The TBM is marginally larger than the 17.48m diameter Hitachi Zosen EPBM on the Alaskan Way viaduct replacement highway tunnel project in Seattle.

In 2013 WWL ALS delivered the TBM Jessica from Stepney Green, through to Limmo Peninsular in east London as part of the Crossrail's Eastern Tunnels contract, C305. The contract from the contractor Dragados Sisk Joint Venture (DSJV), was to transport the 1,300t Herrenknecht S-721 TBM and backup equipment in as large individual components as possible.

Extensive surveys were undertaken by WWL ALS to determine possible routes for this project. As part of this planning process innovative 3D laser mapping was used on dual carriageway sectors of the route with high traffic density, for scanning overhead gantry, bridge and tunnel heights and widths where manual means of checking clearances would be too hazardous. The route taken by all loads was eastbound via the A13 Limehouse Link Tunnel, with a height and width clearance of just a few centimetres for the largest items.

"We spent two nights in the tunnel measuring it, making sure that we were not going to bang into the ceiling," says Eaton. "It's always nerve wracking when you've measured it, but before we left the site we were erected with scaffolding that was just lower than the bridge height, and we knew if we fit under that then we should just fit in the tunnel. It was another exercise to make sure we had done our homework."

All: TBM transportation in London, UK

EAST LONDON TRANSPORT

For Crossrail, WWL ALS utilised an assortment of low loader and semi low loader vehicles,, with a maximum gross vehicle weight of 114t, and the time taken from collection to delivery of cargo was on average 90 minutes per movement. The largest items were transported towards the end of the project, involving loads with maximum dimensions up to 18.20m long, 7.10m diameter wide, 4.35m high and maximum weight 72t.

The route taken also involved travelling contra-flow on a 750m section of this major arterial route (A13) for the two largest loads. "Originally, TfL said we can't go on the other side of the road because it will cause too much destruction, but in the end the Metropolitan Police acknowledged that roads are shut down for marathons, for all sorts of things, and that they had to meet us halfway. It was a long job to do it, we had to think about what actually needs moving in terms of street furniture - such as traffic lights, sign posts and bollards."

Due to the congested nature of the inner-city route, between

seven and 12 police escort vehicles were required for each abnormal load movement in addition to the private escorts provided by WWL ALS. The delivery of the TBM was made over a four week period, with restrictions on when the loads could be moved.

"The two widest pieces were a Sunday morning move. Since we had to cross over to the wrong side of the dual carriageway in a very populated area, it wasn't going to happen with a lot of traffic around," says Eaton. "But all the other moves were a night-time move. We left Stepney Green at 10 o'clock at night, and then travelled the route, but at that stage the police officers were very used to us and knew where the issues would be, so it became a well oiled run."

WWL ALS went through nine months of intensive planning to determine a suitable route, obtain permits and liaise with multiple statutory authorities regarding the removal of street furniture, traffic management and street parking suspensions. The process required WWL ALS' Project team to secure the necessary Be16 Special Order, VR1 and TTRO permits. However, the street parking suspension caused the most difficulties, and that's due to the public ignoring the restrictions.

"We had signs that went up telling people not to park so we could make that left hand turn. The first time we moved the vehicle we had 15 police officers allocated to the convoy, two car lifters and we moved 50 cars before we could get down the road. No matter how much planning you do, sometimes the general public will ignore everything."

Eaton adds that one night a car crash on the route delayed travel while another night they had people come out of the pub on the corner of Jubilee Street and the A13, The George Tavern, which gets used for filming, and leave their cars there for the night. "So while we had these parking embargos, and street traffic lights on lock so we can move the trucks, the film crew had parked up for the night and all gone home, which meant we couldn't get round the corner," adds Eaton. "We had to start calling the film crew and we had to get the police involved. Every day was different."

DOWNTOWN SAN FRANCISCO

For the San Francisco Municipal Transportation Authority (SFMTA) Central Subway project, part of the contract for Contex Shipping was to transport two TBMs from San Francisco Pier 80 three miles downtown to the jobsite, Fourth Street between Bryant and Harrison Streets. Since Pier 80 does not have heavy lift cranes, the firm had to discharge the pieces with the vessel's gear and load

directly onto the trucks. To move the 130t piece Contex Shipping had to rent two mobile 350t cranes to lift from the vessel onto a Goldhofer truck.

"We had to bring the TBMs from the pier through Chinatown, which of course is a busy area, to the jobsite. Every time there was a concert on we couldn't move the machine, and we also had travel curfews during baseball games and rush hour. We travelled mainly at night," explains Bennet Riemeier, VP, Contex Shipping. "One time, we had to cancel a tuck transport because there was a concert that went on longer than planned, and then there was too much traffic. We had to park trucks with the components next to the shaft and wait until the job site was allowed to open the shaft. The shaft that we had to lower the machines into was under a highway; so during the day and rush hours it was covered in order for traffic to flow."

Contex Shipping handled the total transport of the Robbins TBMs – two 6.3m diameter EPB TBMs named Mom Chung and Big Alma – from Robbins' manufacturing facility in Guangzhou, China, to the jobsite.

Riemeier adds: "It took us a day or two to load the barges in China, then it was 10 - 12 hours travel to Hong Kong. It then took a day or two to load the ocean vessel, and a further 32 days to travel from Hong Kong to San Francisco.

"The challenge was to coordinate with the barge company the loading address, and the ocean vessel in Hong kong to be there at the right time in order to avoid detention charges from either barge or ocean vessel operator. You never want to have an ocean vessel wait somewhere for your cargo; either you pay detentions to the ocean vessel, which you really don't want to do, because otherwise you're looking at USD 30,000 to USD 40,000 per day, then on the other hand you don't want to have your cargo sit there for 10 days or longer and wait for the ocean vessel because the barge costs money every day too."

With a complex TBM delivery, Riemeier explains that a freight forwarding company is a clear path to take. When you have just a container from port to port, that's easy to do that by yourself, you'll probably get cheaper rates. But when you have a USD 30M project, you don't want to deal with several companies. Our great advantage is that we're in this market and we speak to these companies every day. For the San Francisco project we were dealing with the barge company, the trucking company in China, the port operators, the shipping line - there are so many different people you need to talk to in order to get this transportation accomplished. It's hard for a company that is not focussed on these things such as TBM manufacturers, which are more honed in on creating these machines"

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What's on

2016

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

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

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

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

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

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

Underground Singapore 2016
29-30 September 2016
Singapore
Underground Singapore is a Conference Organised by the Tunnelling and Underground Construction Society (Singapore) and supported by the Centre for Soft Ground Engineering, National University of Singapore. The purpose of the Conference is to provide a forum for the discussion of issues relevant to the design and construction of underground works in Singapore.
www.tucss.org.sg

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

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

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

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

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

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

2017

Rapid Excavation and Tunnelling Conference 2017
9-16 June 2017
Bergen, Norway
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. It boasts an impressive programme.
www.wtc2017.no

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. Preparations are already on the way for Stuva Expo 2017, which will take place in Stuttgart.
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.
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.

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

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

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
Having completed tunnel excavation on Europe's largest infrastructure project this year, much experience has been gained by the UK tunnelling industry. This meeting will give a summary of the lessons learned from the project and follows on from a paper that was presented at the World Tunnel Congress in San Francisco earlier this year.
Speakers: Bill Tucker and Mike Black, Crossrail

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

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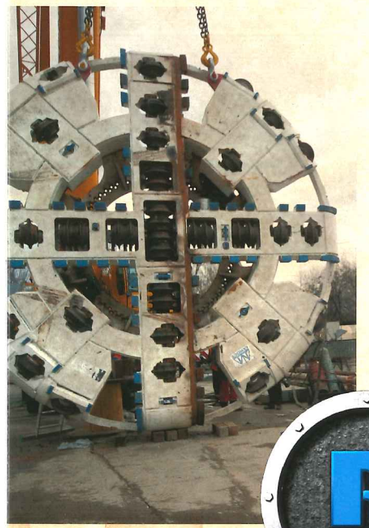

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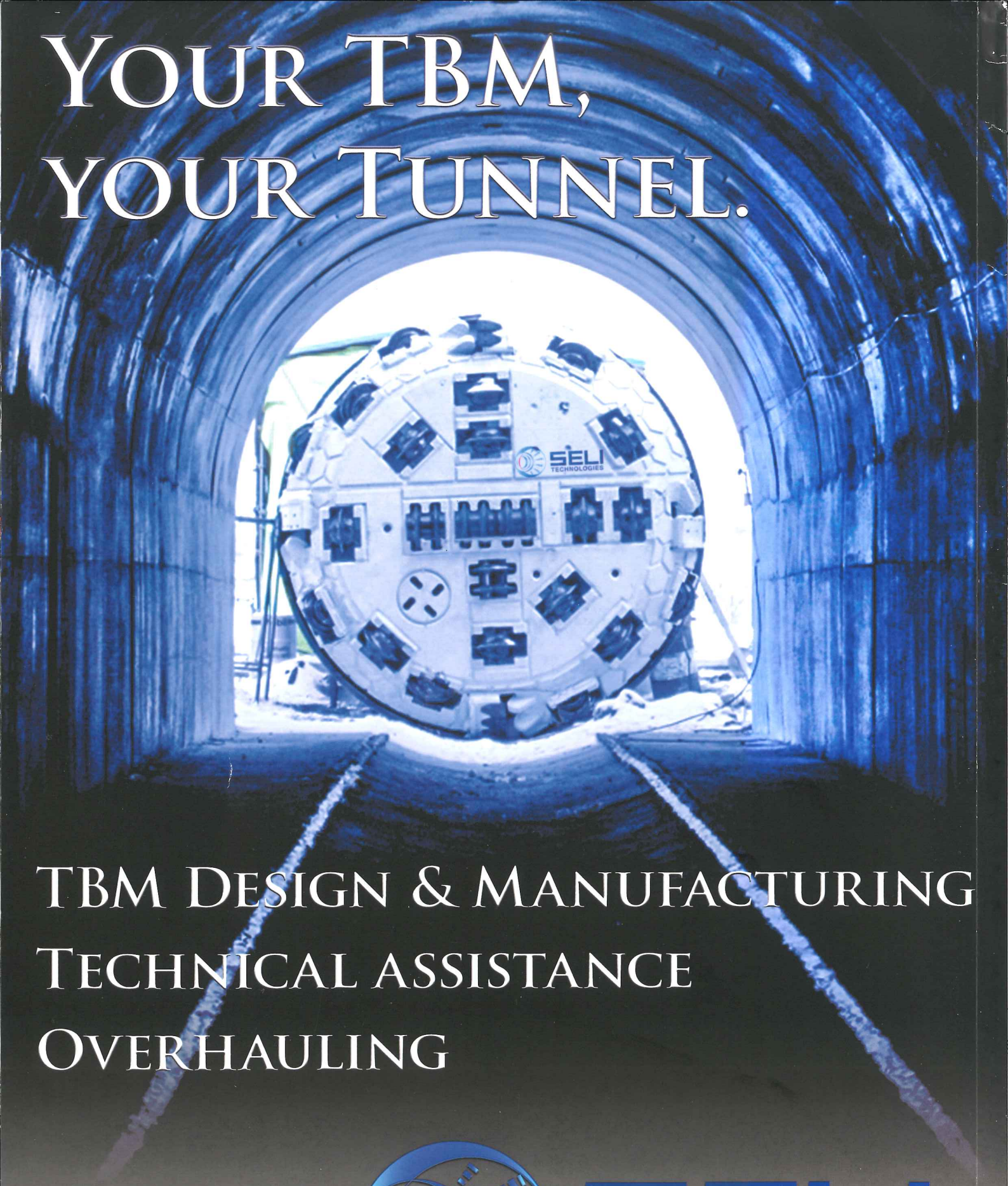

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