

INTERNATIONAL EDITION

July 2017

Tunnels

AND TUNNELLING



CROSSRAIL C510

*Whitechapel and
Liverpool Street*

Conquering

Connecting Norway by rail: 5 Herrenknecht Hard Rock TBMs are on the move for **45 km of new first-class rail tubes** at the New Ulrikentunnel and Follo Line projects.

Toughest

Biting its way through the Scandinavian stone, the TBMs are facing the absolute **hardness test** when dealing with up to **350 MPa** rock strengths. Equipped with excavation tools for such a demanding mission, the Herrenknecht TBMs will complete all their tasks.

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MAGIC NUMBERS

It is a completely arbitrary number, pleasing only because it plays into a base 10 counting system, but compound growth of 7% results in a doubling time of 10 years. That's what the growth of the tunnelling industry currently stands at according to the International Tunnelling Association (ITA), 7% per year which is expected to continue for the near future. Or at least the next five to 10 years.

At the World Tunnel Congress in Bergen, Norway this year, the ITA released its Tunnel Market Survey, which contains data from 89 countries and 2,300 tunnel projects. It has been a difficult project, with incomplete but fairly reliable data from some countries, while others such as China have proven challenging even for local engineers. However, the booklet released by the ITA has some interesting numbers.

Construction being generally considered 10% of global GDP (gross domestic product – the total value of all goods and services produced within an economy), in 2013 the global GDP of USD 75 trillion saw a construction output of USD 7.5 trillion. Construction grew by 3.9% per annum and hit around USD 8.5 trillion in 2016.


Tunnelling is growing nearly twice as fast, hitting that 7% figure and around USD 90bn total market value in 2016, or around 1% of total construction output. This translates into approximately 5,200km constructed a year, which represents a total growth of 15% for the period.

Alex Conacher

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



Projected growth is a particularly slippery statistic owing to the difference in planning times between regions. For example, a project in Western Europe might be planned for decades before ever a shovel enters the ground, but China can plan, construct and commission a project within a handful of years. Nevertheless, the ITA predicts around USD 770bn of output over the next eight years, with Europe representing 36% of these projects and China representing just 15% for the reason given. China still represents around 50% of global work for the near future.

In summary, the Middle East has greatly increased in value, Europe is flat, North America has shrunk, China has grown, but shrunk in relative value to other regions, and Latin America still has great potential. Africa has the need for tunnels, but little activity yet. Nigeria is due to become the third most populous country in the world by 2050, but the continent as a whole is expected to have 20 cities with more than two million inhabitants by 2025. Nigeria was welcomed as an ITA Member Nation in 2017 after being founded in 2015. The move can only be a positive for the itself and its neighbours. 

This month...

30 YEARS AGO

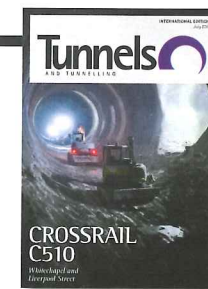
American States interested in accommodating the USD 4.4bn Superconducting Supercollider planned for the US must have their proposal with the Department of Energy by 3 August 1987. This nuclear experimentation facility, with about 52 miles of tunnel and six underground chambers, will be the largest atom smasher in the world when complete. The DOE has said it will encourage widespread cooperation within the tunnelling industry to help states prepare their proposals. However, consultants that assist with a state proposal cannot then be engaged in DOE excavation. *Tunnels and Tunnelling*, July 1987, page 9

40 YEARS AGO

Next spring work begins on the 757m centre section of the Keiyo Railroad's Daiba Railway Tunnel in Japan. The new section will run under the sea between two islands, and post-tensioned cables are to be used to seal the rubber joints instead of welded steel or reinforced concrete. The designers claim that these cables will be flexible enough to accommodate the bed soil settlement estimated as being up to 1.2m. Prefabricated tunnel elements built by Ishikawajima-Harima Industries and Mitsubishi Heavy Industries will be sunk by a joint venture consisting of the Kajima Corporation, Tekken Construction and Sato Kogyo. The Keiyo Railroad's Daiba Railway Tunnel will be 4.78km long and the centre section, which will be a double track rail tunnel, *Tunnels and Tunnelling*, July/August 1977, page 27

Cover

The front cover shows the SCL-lined environment at Crossrail's Liverpool Street Station.



Next issue

In the next issue of *Tunnels and Tunnelling International* we have an interview with Guilia Viggiani, recently arrived at Cambridge University, a report from the Thessaloniki Metro, and a look at Portuguese health and safety statistics.

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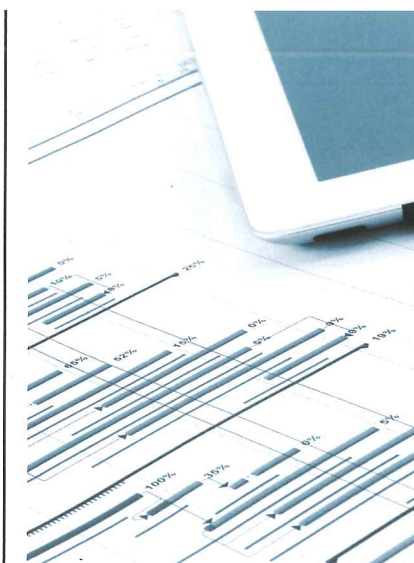
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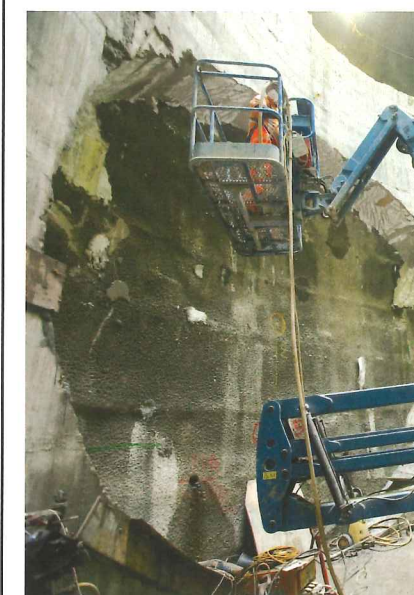
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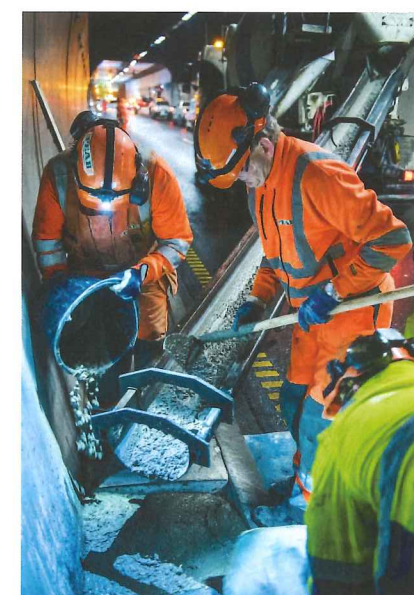
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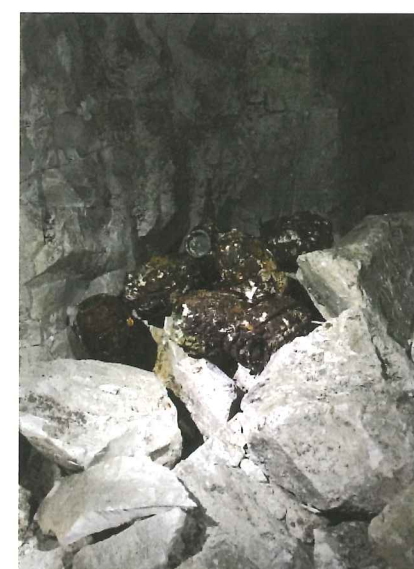
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With over 200 tunnels up for refurbishment in Norway before 2020, T&T looks at the Taasen tunnel as a case
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A look at some of the options available in construction equipment released at Conexpo this year
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Events and contacts

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CONSTRUCTING A SUSTAINABLE FUTURE

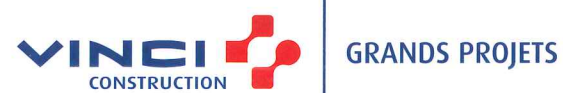
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SYDNEY HARBOUR CROSSING AWARDED

AUSTRALIA — A JV of CPB Contractors, John Holland and Ghella has been awarded the new metro crossing below Sydney Harbour. Ghella takes a 10% share, with CPB (a CIMIC company) and John Holland splitting the remainder equally.

The AUD 2.81bn contract is for twin 15.5km tunnels and associated civil works, part of Stage 2 of the Sydney Metro project.

Some 57 cross passages will be required, spaced approximately every 240m along the tunnel.

Also required is a temporary access shaft and tunnel dive structures at Chatswood and Marrickville, a crossover cavern (for trains to cross between tracks) and six new underground stations.

Excavation works are expected to commence within weeks and the contract should be completed in mid-2021.

CPB Contractors and John Holland previously worked with Dragados to build

15km of twin tunnels for the Sydney Metro Stage 1, an AUD 1.15bn contract.

Transport for NSW conducted geotechnical work deep under Sydney Harbour to help determine the best way to deliver the new metro railway tunnels, taking rock and soil samples from more than 50 boreholes.

These geotechnical works settled the decision to use TBMs to tunnel through a combination of sandstone, clay and sediments between North Sydney and the new metro station at Barangaroo.

Five TBMs will be used to excavate the 15.5km twin railway tunnels from Chatswood to Sydenham, including four double-shield, hard rock, gripper type TBMs and a slurry machine.

The TBMs will have a 7m diameter cutterhead and as they excavate each 1.7m section of tunnel, a vacuum lifting device will install six concrete segments on the walls to form a ring. Once constructed the internal tunnel diameter

will be 6m.

Additional geotechnical investigations will be undertaken as part of detailed design.

The geology along the entire project alignment, which includes the tunnels and the station civil works, is 83 per cent sandstone, 10 per cent shale along with sedimentary deposits.

The five TBMs will excavate through rock which is made up of 93 per cent sandstone.

Tender is underway to select a TBM supplier. The first of the five tunnel boring machines will be in the ground before the end of 2018.

Detailed design is underway on the segmental lining for the excavated tunnels to determine the optimum concrete mix and waterproofing requirements.

A precast facility will be set up at Marrickville to produce about 99,200 concrete segments needed for the project.

Federal agencies find California's Delta Tunnel safe for endangered species

USA — The Fish and Wildlife Service (FWS) and National Marine Fisheries Service (NMFS) have both found the Delta Tunnel project, as proposed by the California Department of Water Resources and the Bureau of Reclamation, will not harm endangered species. The greenlight from each agency on 26 June is one of many needed to build two tunnels conveying water from the north to the south Delta. Also called the California WaterFix (CWF), the proposal would modify the point of diversion for the State Water Project (SWP) and Central Valley Project (CVP) in the Sacramento-San Joaquin River Delta, and includes three intakes, two 35-mile-long (56km) tunnels, associated facilities, among other work; as well as operate existing south Delta facilities in coordination with these new facilities.

The Bureau of Reclamation (Reclamation) and the

California Department of Water Resources (DWR) coordinate the operation of the CVP and the SWP, respectively, and are also the lead agencies for the CWF. The agencies were charged with evaluating the effects of the proposed CWF on species listed under federal protection and their designated critical habitats.

NWS said in its statement, "We have concluded that WaterFix will not jeopardize threatened or endangered species, or adversely modify their critical habitat. We have documented some impacts from construction, and have worked with the Department of Water Resources and the Bureau of Reclamation to develop a plan to restore habitat to minimize and mitigate those impacts.

"We also believe WaterFix will, by routing water supply through the tunnels, reduce entrainment of fish from the State and Federal water pumping facilities in the south Delta, which has been a concern in the past. In addition, we recognize that a number of future decisions will address

important details related to WaterFix construction and final operations, especially the new water management operational plan for the Central Valley Project and State Water Project and habitat restoration in the Bay Delta.

NMFS' final biological opinion concludes that construction and operations of CWF as proposed would not jeopardize the continued existence of endangered Sacramento River winter-run Chinook salmon, threatened spring-run Chinook salmon, threatened North American green sturgeon, threatened California Central Valley steelhead and endangered Southern Resident Killer Whales, which depend heavily on Chinook salmon for food.

"Our staff have worked diligently with our partners to make certain, through a robust scientific and technical analysis, that this project conserves listed species," said Barry Thom, regional administrator for NMFS' West Coast Region. "We will continue to work together to monitor the project's progress and implement adaptive

management measures when necessary."

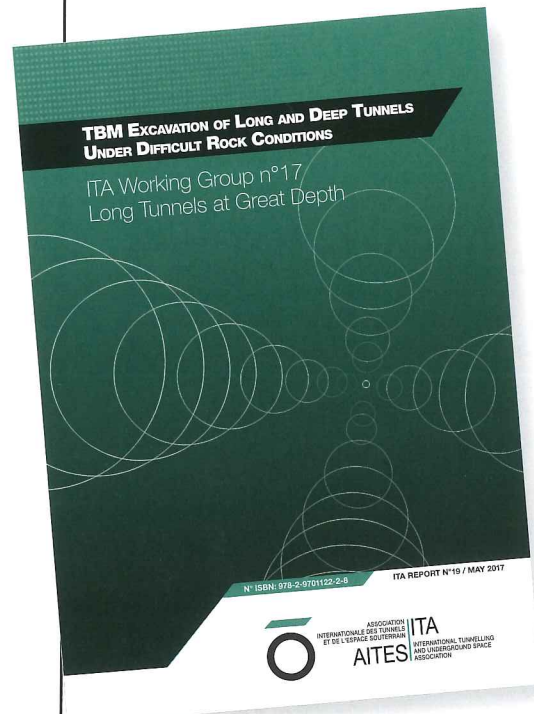
Fort Wayne delegation celebrates ceremonial start to tunnelling works

USA — The mayor, Tom Henry, and members of the Fort Wayne City Council, along with staff from the Utility Advisory Group, and contractors S.A. Healy Company and Salini Impregilo, among others, attended a ceremony to mark ground breaking for tunnelling on 15 June.

The combined sewer overflow (CSO) mitigation project includes a 5-mile (8km) main tunnel approximately 160 to 180ft (48.7 to 54.8m) deep in bedrock. There is another a mile of consolidated sewers near the surface connecting to drop shafts that will drop the combined sewage into the main the tunnel.

There will also be approximately 2 miles (3.2km) of sewer that will connect to the south end of the tunnel that will be shallower and smaller in diameter.

ITA WORKING GROUPS RELEASE NEW GUIDANCE



INTERNATIONAL — Two new documents have been released by International Tunnelling Association (ITA) Working Groups this year. ITA Working Group 6: Maintenance and Repair has released a report on structural fire protection for road tunnels, while ITA Working Group 17: Long Tunnels at Great Depth has released a report on TBM excavation of long and deep tunnels under difficult rock conditions.

ITA Working Group 6 said of the reason for creating the report: "Between 1990 and 2010, there have been a number of serious underground fires in road tunnels. These fires have caused extensive loss of life and severe collateral loss to the infrastructure. Aside from the tragic loss of life, the long-term effects to the local infrastructure, the loss of public confidence in the safe use of tunnels have necessitated the development of safety recommendations.

"The document is intended for use to identify the categorisation of road tunnels and propose methods for the protection of the structural elements. The behaviour of structures is a key factor to allow users to evacuate and rescue personnel to enter the scene and effectively perform their required duties and to limit damage to the tunnel. Improved specifications for tunnel fire resistance are required in order to mitigate the consequences of a serious fire, which could result in structural failure or complete collapse."

On the scope of the document, the group added: "As an addition to PIARC guidelines, the scope of the document is to provide recommendations for techniques and materials to answer these structural requirements and make tunnels and their ancillary structures more resistant to fire damage.

"These recommendations take into consideration the time - temperature curves as recommended by others and develop suitable means and methods for the protection of the structures.

"The aim or focus of the protection may vary from preventing minor damage to preventing a total collapse both

during the re event and during the rescue operation.

"The document is intended to be a guideline and is to be used for road tunnels only and not for rail, mass transit, or pedestrian tunnels.

"However, the basic principles for the protection of tunnels and underground structures may be applied to other types of structures; in such cases special consideration must be given to the particular application and its own unique operational and other site-specific elements."

The Working Group 17 report opens with reference to the challenges of high overburden and great length for TBM tunnelling on, effectively, base tunnel jobs. The group quotes Professor Bieniawski speaking at WTC 2014 in Brazil, "For tunnel boring machines (TBMs), the use of which will be more extensive, the challenges will be to bore tunnels under high rock pressures and high water pressures, both in hard rock and in soft ground conditions; these challenges are simply extraordinary."

The group goes on to list the three aims of the report:

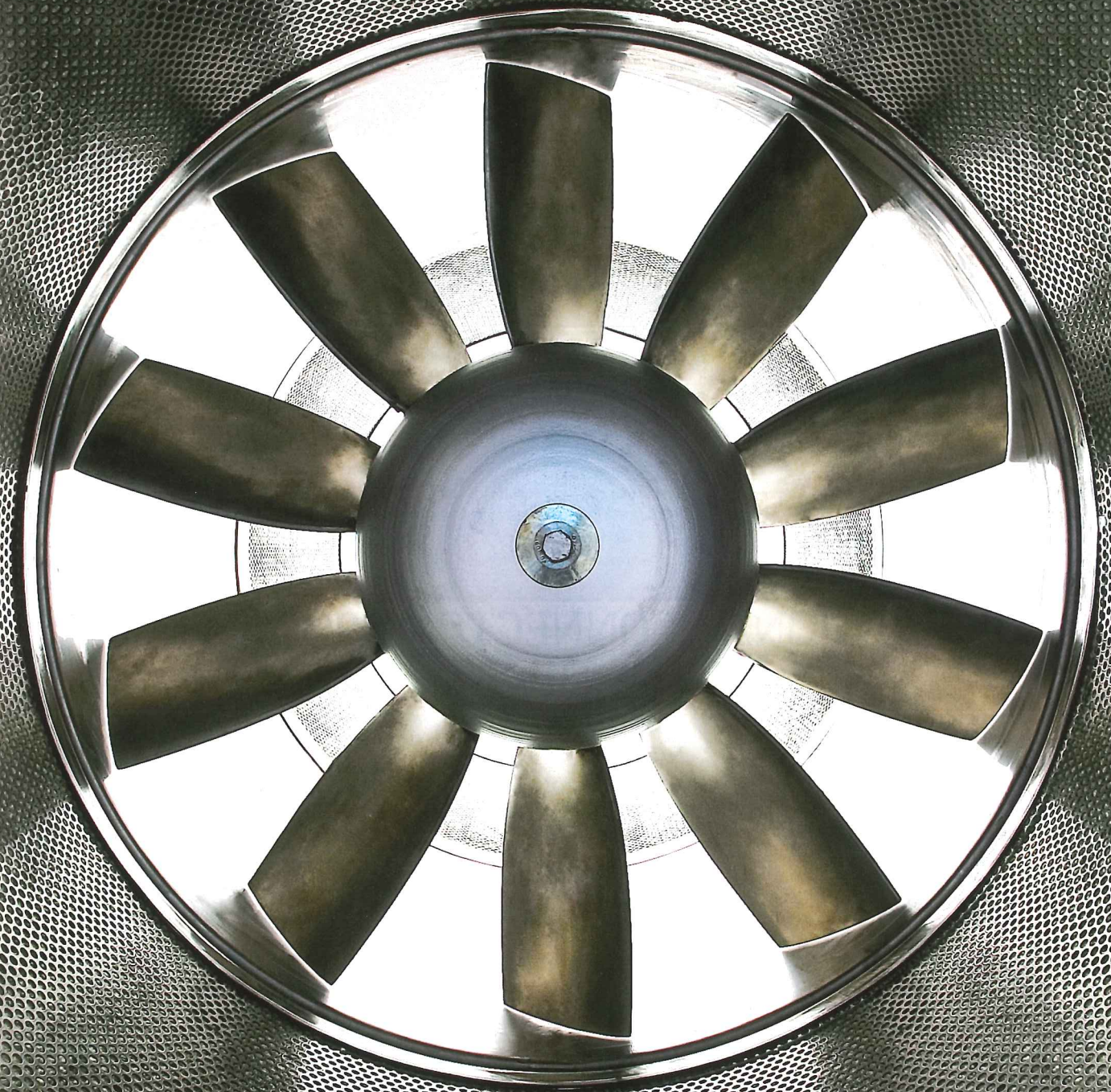
- To introduce a common technical language and a simplified classification on the main geotechnical hazards that may be encountered during the excavation of long and deep tunnels crossing difficult rock conditions;
- Analyse the influence and the consequences of these phenomenon regarding the various TBM types;
- Provide recommendations for the design, for the selection of the TBM type and for the mitigation measures to be implemented on-site.

All ITA Working Group publications can be found in the Working Groups section of the ITA website (navigate to the relevant group and there should be an 'all publications' link. Publications by Working Groups 6 and 17 can also be found through the following links:

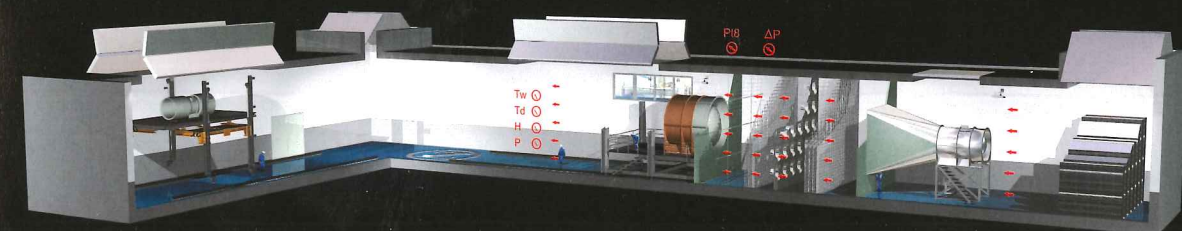
<https://about.ita-aites.org/publications/wg-publications/content/11/working-group-6-maintenance-and-repair>

<https://about.ita-aites.org/publications/wg-publications/content/22/working-group-17-long-tunnels-at-great-depth>

Above: The front pages of each of the new documents, available in PDF from the ITA website



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NY governor orders accelerated tunnel repairs

USA — New York's governor Andrew Cuomo announced on 12 June orders to accelerate construction on bridges and tunnels in the region, in anticipation of added traffic due to Amtrak emergency repair work.

He called for major construction projects to be complete by July 8 to mitigate the impact of additional vehicles on the road this summer.

"Our top priority is ensuring all New Yorkers can get where they need to go as quickly and easily as possible this summer and we're taking every conceivable step to prepare for Amtrak's summer of hell," Cuomo said. "By aggressively expediting construction we are taking action to ease commutes and

provide New Yorkers with peace of mind."

A special interagency team, composed of the governor's Office, the Department of Transportation and the MTA, is overseeing the expedited construction. In May, Cuomo directed the MTA to develop a comprehensive mitigation plan to combat the Pennsylvania Station summer crisis.

Amtrak is proposing repairs that would reduce the number of trains at Pennsylvania Station by approximately 20 per cent during peak travel times and as a result, commuters searching for alternative methods of transportation will crush an already overburdened subway system and clog roads and bridges.

Affected tunnels are the Queens-Midtown Tunnel and the Hugh L. Carey tunnel, which saw damage following the 2012 Superstorm Sandy.

Dariali commissioned

GEORGIA — In April 2017, a ceremony was held to celebrate the commissioning of the Dariali Hydropower Project in the Republic of Georgia.

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

The Dariali HPP gathers water from the Tergi River and directs it through the headrace tunnel to the power house located near the Russian-Georgian

border. Each year, the site will generate 500 GWhs of carbon-neutral energy, with 70 percent of power production occurring during the country's summer months. Robbins also invested in the project by gaining equity through supplying tunnelling equipment and services in consortium with contractor Peri. "Robbins understood the risk in the tunnelling portion of the project and we were compensated for taking on part of the risk. Peri is a long-time customer, as we supplied a TBM to them 15 years ago for a small project in Georgia. It was great to be invited to invest and risk share on this project, and to work together again," said Robbins president Lok Home. The 5km-long headrace tunnel for the power station was bored with the use of a 5.5m-diameter Robbins Main Beam TBM starting in February 2012.

REGIONAL CONNECTOR PROJECT MAKES MILESTONE

USA — The TBM excavating twin tunnels for the Regional Connector project in Los Angeles broke through to the Grand Ave/ Bunker Hills Station at 2nd/Hope on 1 June.

Launched, last winter the TBM start mining in early February and in late April it completed digging through the Historic Broadway Station at 2nd and Broadway on its way to 2nd Place and Hope.

The Los Angeles County Metropolitan Transportation Authority said following the breakthrough, the TBM will be repositioned inside the station box area to continue tunnelling the remainder of the first tunnel to 4th Street and Flower. The TBM will then be taken apart and transported back to the 1st and Central Station site where it will be reassembled in order to begin mining the second tunnel.

The USD 1.75bn Regional Connector Transit Project is a 1.9-mile (3km) light-rail tunnel that will connect the Blue, Expo and Gold Lines in downtown Los Angeles and will include three new stations at 1st Street/Central Avenue, 2nd Street/ Broadway and 2nd Place/Hope Street. The project will reduce the need for light rail riders to transfer and speed

up trips to and through the city.

When complete in 2021, the Connector tunnels will allow Metro to run one light rail line between Azusa and Long Beach. The other line will run between East Los Angeles and Santa Monica. The two lines will share five stations in DTLA: Pico, 7th/Metro and the three new underground stations being

constructed as part of the Connector project.

The TBM was manufactured in Germany by Herrenknecht AG and is 21.6ft (6.9m) in diameter.

It has advanced about 70ft (21.3m) per day on average. Completion of the twin 1.1-mile (1.78km) tunnels is expected in early 2018.



Above: Tunnel eye under construction on the Regional Connector project

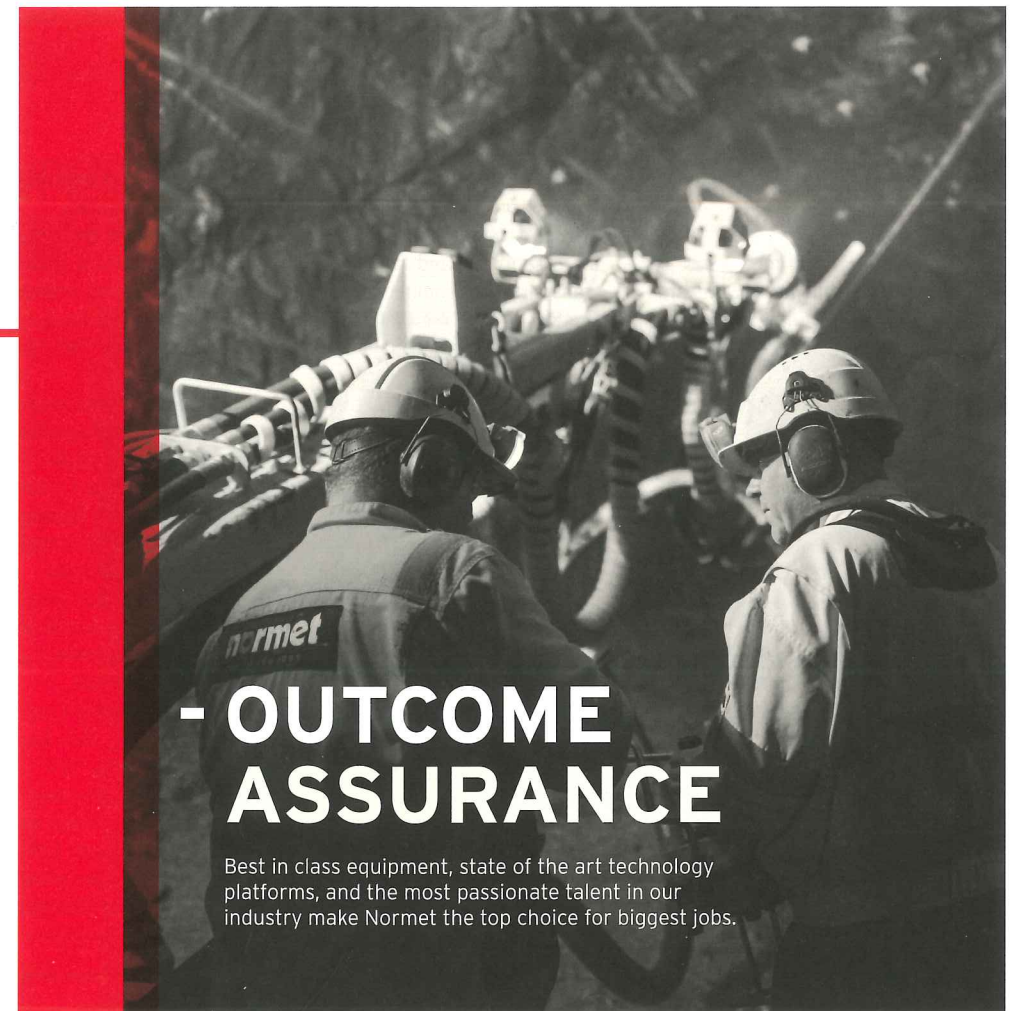
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Four groups in contest for Zojila Tunnel

INDIA — Local media has reported that four teams are in the running for the Zojila Tunnel contract in Jammu Et Kashmir, northern India. These are: a JV of Reliance Infrastructure and Dogus Construction; Larsen and Toubro; IL&FS Engineering and Construction; Jaiprakash Power Ventures

The tunnel will reportedly run for around 14km and cost around USD 1.5bn. Previously it has been hard to attract bids on the project. The project is remote and extremely exposed to the elements, being at an altitude of 3,500m above sea level.

The mountain pass connects Sonamarg in the Kashmir valley with Drass and is crucial for maintaining supplies to armed forces stationed all in the disputed region, as well as the civilian population of Ladakh. The pass remains snowbound for more than five months in a year.

DLZ makes acquisition

USA — DLZ has announced on 30 May the acquisition of WMB Consulting Engineers. Formerly known as Wright, Morgan, and Brown, WMB Consulting Engineers specializes in the planning and design of rural and urban highways, interstates, and bridges. WMB has been serving clients in the Commonwealth of Kentucky since 1957.

The acquisition of WMB demonstrates DLZ's continued growth strategy to meet the increase in demand for transportation engineering services in the Midwest region, the company said. With existing DLZ offices in Louisville and Frankfort, this acquisition expands the firm's footprint in the market, offering a larger local presence to serve clients in Kentucky. Vikram (Raj) Rajadhyaksha, CEO of DLZ, stated, "WMB's exemplary professional engineers are an exciting addition to our team and they bring decades of experience in designing signature projects for the Kentucky Transportation Cabinet (KYTC)."

Aldea makes Toronto appointment

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

"Angel's experience from his work on major projects around the world is an important addition to the Aldea Services team," said senior vice president Bob Goodfellow. "His exceptional knowledge of tunnel lining design and the modeling of tunneling impact on adjacent structures will serve our clients very well. Given the

varying tunneling techniques and materials that are employed around the globe, Aldea's international team experience gives us a broader perspective and increased possible design options to bring to the table."

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

"I feel that being a part of this team is a big step for me," del Amo said. "It's exciting to have this diversity of ideas and experience to bring to our projects. I know it makes for a better effort end result for our Clients and ultimately local taxpayers."

Joy acquisition

USA — Komatsu America Corporation has completed its acquisition of Joy Global a mining machinery company. Retaining its headquarters in Wisconsin, Joy Global was renamed Komatsu Mining Corporation and is now operated as a subsidiary of Komatsu. The ribbon cutting was held in May.

"The combination of our Komatsu-brand surface mining equipment with the P&H, Joy and Montabert brands of surface and underground products will allow us to offer a complete range of mining solutions for

our customers," said Tetsuji Ohashi CEO of Komatsu.

Queen's Speech commits to HS2 leg

GREAT BRITAIN — The Queen has committed the government to investing in High Speed Two (HS2). In the 2017 Queen's Speech, a traditional way in which the priorities of government are announced to the nation, the UK's head of state briefly touched upon the project amidst an array of other ideas.

"My government will work to attract investment in infrastructure to support economic growth. Legislation will be introduced to ensure the United Kingdom remains a world leader in new industries, including electric cars and commercial satellites. A new bill will also be brought forward to deliver the next phase of high-speed rail."

The comments refer to Phase 2a, which will extend the link from Birmingham to Crewe.

Final Quito launch

ECUADOR — Acciona has announced that the third 9.37m-diameter TBM has been launched on the second phase of Line One of the Quito Metro. The line will eventually comprise 22.6km of tunnel and 15 stations.

The first of these machines has been operational since March and has excavated more than 2.1km of tunnel. The second began excavating in May and has bored 300m.

STRABAG BOASTS RECORD ORDER BOOK

AUSTRIA — Contractor Strabag announced that its order backlog on 31 March 2017 had passed the EUR 16bn mark for the first time in the company's history. The full value of the work was EUR 1,611,313,000.

The company said that this was partly due to numerous new large orders from the public sector and industry in Germany, as well as several new projects

in different construction segments in Central and Eastern Europe.

Strabag experienced its usual winter loss, albeit reduced, but expects to make it up in the warmer months. Strabag president and CEO Thomas Birtel added, "As usual in the construction sector, the first quarter does not allow us to draw any conclusions for the full year.

"Still, the figures for the first three

months of 2017 – and especially the renewed record order backlog of more than EUR 16 billion – reinforce our decision to confirm the existing outlook: The output volume is expected to rise and the EBIT margin should reach at least 3 per cent. The development of the business in the weeks after the quarterly reporting date also supports this forecast."

INTERCEPTOR PROJECT SEES TBM ACCEPTANCE

USA — The TBM for the 1.89km Ohio Canal Interceptor Tunnel has undergone factory acceptance. The 9.26m Robbins machine, a hybrid EPB / hard rock single shield machine was subsequently shipped the 40km from the factory in Solon, Ohio to the worksite in Akron.

The audience at the factory acceptance included Akron Mayor Daniel Horrigan, Robbins chief engineer Dennis Ofiara, and David Chastka, project engineer for contractor Kenny-Obayashi JV.

The machine will be launched at a depth of 12m into 68m of soft ground before entering a 183m-long zone of partial-face shale, after this the machine will switch to hard-rock mode for the remainder of the drive, which will be through a full face of shale. Continuous probe drilling will inform the changes.

Muck removal will be achieved with a durable screw conveyor, the first flight of which is covered welded-in wear plates. The auger shaft is lined with hard facing in a crosshatch pattern, while the screw conveyor casing has been similarly lined in wear plates and hard facing. A wear monitoring plan has been prepared for the entire drive in order to maximise efficiency in the section of more abrasive rock.

A spokesperson for Robbins added: "Unique aspects of the machine include a versatile cutterhead that will be configured with consideration for both the short soft ground section and the longer section (about 65% of the tunnel) in hard rock. A combination of disc cutters and sacrificial rippers will be used in case a cutter becomes blocked. The required rolling torque of the disc cutters has been reduced by 25% to encourage smooth rotation in soft ground. The motors of the Crossover XRE machine have been reworked from an original EPB configuration to permit higher motor speed at reduced torque for the open mode segments of the drive."

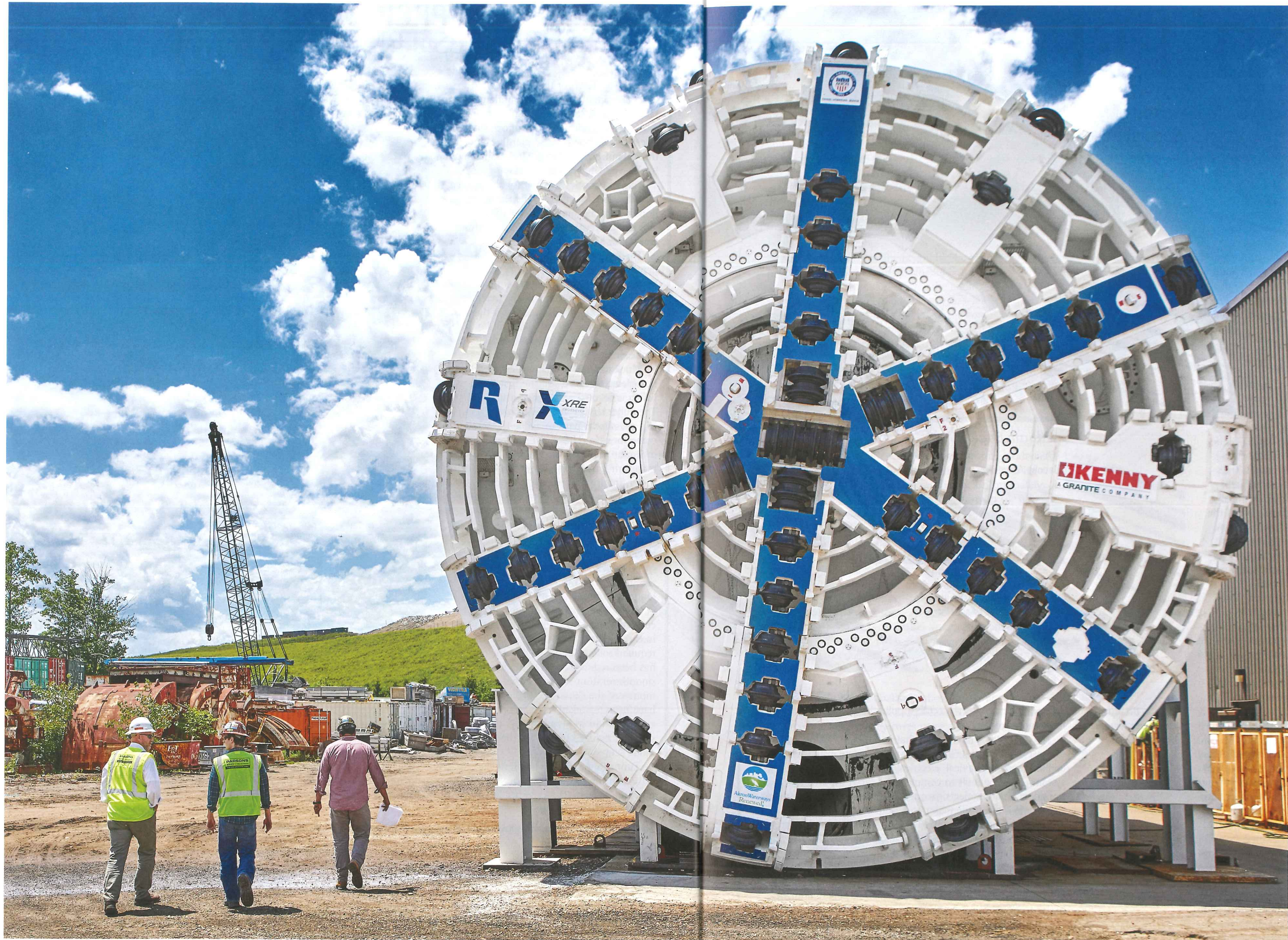
Tunnelling is due to begin in August 2017 and the tunnel is scheduled to be operational from 31 December 2018.



From top to bottom: Factory acceptance of the interceptor tunnel project TBM was held just 40km from the jobsite. The machine is the first of Robbins' Crossover range to be sold on US soil

Correction

Last month *Tunnels and Tunneling* published a feature on the Northern Line Extension project and neglected to mention OTB Engineering. OTB was the designer for all the complex tunnelling works including SCL tunnels, major tunnel temporary works, all SGI lined tunnels, cross-passages, the step-plate junction, the upgrade of Kennington Station. Notably, the company introduced a new way of building an on-line step-plate junction, utilising a hybrid solution both for the permanent and temporary works – a major departure from the traditional methodology.



Left: The cutterhead of the TBM bound for the Ohio Interceptor project. See news, page 13

JOINT EFFORT

Sarah Wilson and William Edgerton of McMillen Jacobs Associates report on use and abuse of the schedule during procurement and construction

OFTEN WHEN A BEST-value procurement is used for construction services, the schedule is a major factor in the technical evaluation. Specifically, for contracts where advancement of the schedule is one of the primary reasons for selecting the design-build delivery method, the owner's rationale for requiring the contractor's proposed work schedule is to examine the proposed approach to executing the work while also ensuring that the contractor demonstrates an understanding of constraints and milestones. This is especially important when there are multiple approaches, or means and methods, that could be used.

Schedule as an element of "best value": Best value is often a trade-off between higher risk and shorter schedule, and the technical evaluation must consider both. In evaluating the schedule, the owner must be able to conclude that the proposed schedule is credible. Making such a conclusion requires an evaluation of whether the specified constraints (e.g., property availability, work hours, permit restrictions) have been respected, as well as an evaluation of whether the durations are reasonable. For tunnel projects, this means not only the assumptions of TBM procurement, but also the assembly, start-up, learning curve, daily production, and tunnel clean-up. Often, the durations of such activities are based upon experience,

Above: Baseline schedule issues can be fixed

as modified by project-specific supplier information, and thus are reasonably accurate.

However, it is a rare project that includes only a tunnel. In most cases concrete structures, and in some instances architectural, mechanical, electrical, HVAC, and other systems, must be built to complete the facilities. On large multidisciplinary projects, frequently led by a tunnel contractor, the tunnel is often the major cost element. For these projects, it is not uncommon for proposal schedules to accurately represent the tunnel activities; however, the remaining "finish" activities are then shoe-horned into the schedule to meet the contract-stipulated completion dates. In such circumstances, the owner may be happy to see that the bidders can finish the project within the contract time frame, but it would serve the owner better to be told that the contract schedule is not feasible given the constraints. Unfortunately, that rarely happens, particularly when schedule is an element of the best value determination.

William Edgerton

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Sarah Wilson

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In such cases, the owner's objectives aren't met by the schedule that is submitted as a part of the technical proposal. This practice also serves the parties poorly during construction when they cannot predict or regain the time needed for later activities, resulting in an impossible situation for which responsibility must then be attributed.

Misuse of the Preliminary Schedule: Another frequent requirement is for the technical proposal to include a "preliminary" schedule. The primary purpose for including such a requirement is to be able to monitor the job while the contract baseline schedule is being prepared. Since the baseline schedule is typically integrated into the schedule of values and thus provides the mechanism for payment, the preliminary schedule provides a basis for payment until approval of the baseline. In addition, early activities, such as permitting and initial design work, must be accurately represented and managed to the plan: time lost in the beginning of the job is very expensive to make up later, and time saved in the beginning is the easiest won.

In approving this preliminary schedule, the owner's primary concern is that the work detailed for the initial part of the job represents sufficient progress so that the baseline schedule will meet contract milestones, including the completion dates. Because the later work is not required to be developed to the same level of detail, the owner has to take a certain amount of this on "faith." Therein lies the reason for the term of the preliminary schedule to shrink over the years. What used to be a 180-day schedule (six months) has been shortened to 120 days, and sometimes even 90 days (three months). When considering the length of time for preparation, review and approval, these times tend to be fairly short, especially for projects with multiple disciplines. The result is that the time available for preparation of the baseline schedule is not sufficient for developing a detailed plan for the (later) work, or for the baseline schedule to be adequately reviewed by major subcontractors. Unfortunately, the result is frequently a deterioration of quality of the baseline schedule: "You get only the schedule product that the contractor has time to do."

Factors affecting the quality of the baseline schedule: It is in the best interest of both parties to reach an early agreement on the baseline schedule. The primary purpose of the schedule is to provide a logical sequence of the work that demonstrates how the contractor plans to achieve the contract completion date, that gives the owner some method to periodically monitor progress, and that gives both parties an agreed-upon approach to determining the effect of changes upon the contract time. Unfortunately, this doesn't always happen, for a number of reasons:

- The contractor hasn't finalised subcontracts for some elements of the work. The bid price must include all elements of the work, but in many cases there are multiple suppliers and subcontractors that may be used to achieve the results. The baseline schedule must include sufficient time for whatever workforce will perform the work. Although it might be preferable for the selected subcontractor to provide input to the baseline schedule, procurement activities may make this infeasible. In such a case the contractor must constrain its procurement by only considering subcontractors that agree to meet the approved baseline schedule. A good contractor will respect this procurement restriction. However, not all contractors will do so faithfully, resulting in a negative impact upon the already-submitted schedule and potentially putting subcontractors at a disadvantage right out of the gate.
- The owner assumes that more activities will yield a better schedule. This is not necessarily true. More activities yield

more complexity, and a greater likelihood that the actual work will not follow the scheduled plan, thus requiring a schedule revision. The "art" of preparing a schedule is to include enough activities to demonstrate and allow monitoring of the plan, but not so many that the view of the forest is blocked by the trees. Appropriate granularity is also relevant to schedule of values preparation and administration. A particularly well-known example of this is the often specified maximum 20-day activity duration. For tunnel projects, where the "mine tunnel" activity may take many months, it becomes more reasonable to supplement the long "mine tunnel" activity with a linear schedule. This is a much-better schedule model for monitoring progress.

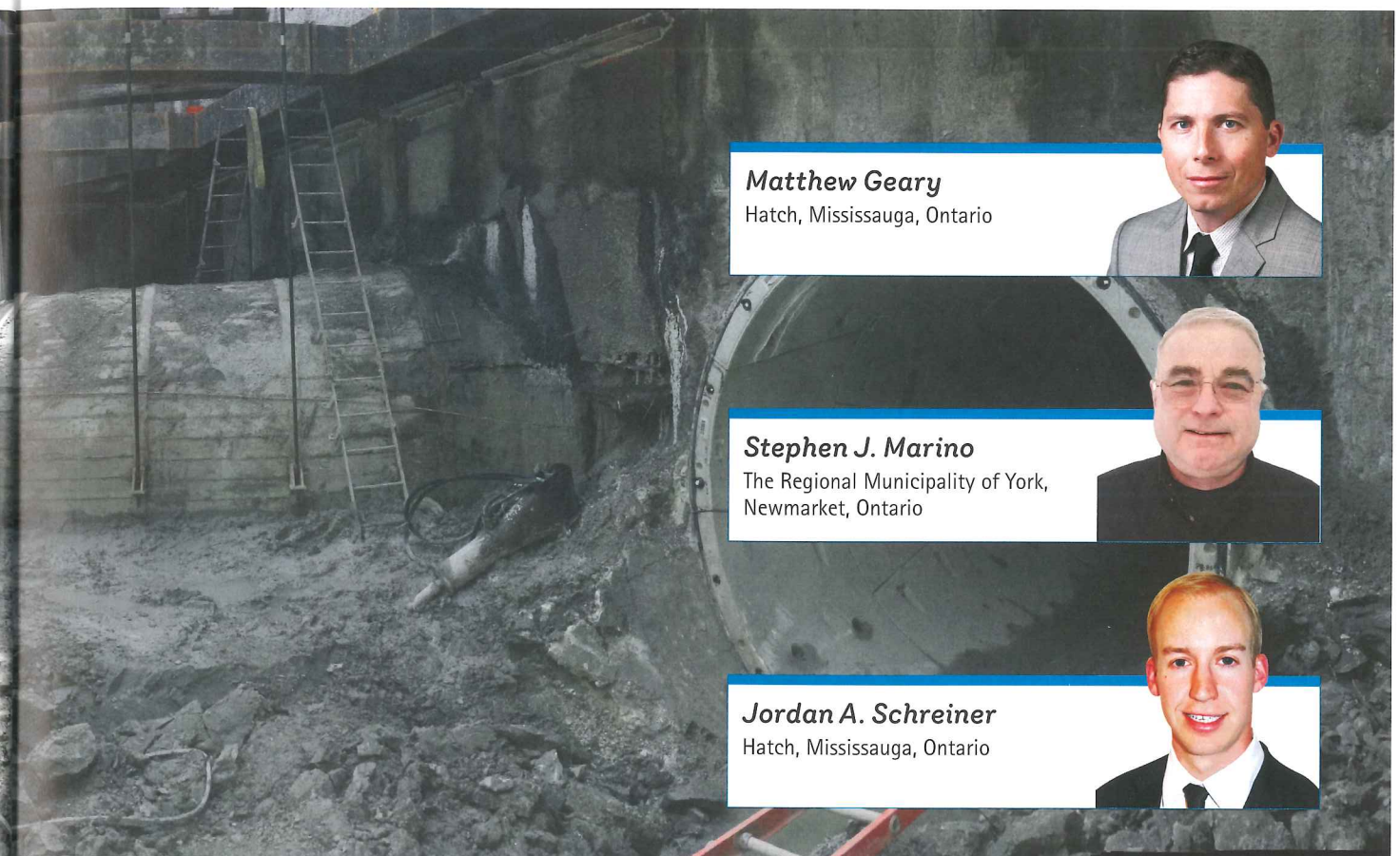
- The scheduling software no longer fulfils its purpose. The software has become so advanced and the rules for what can and should be done are so arcane, that the schedulers (for both contractor and owner) are more technicians than "construction people." Although the resultant document may comply with the specifications, the content is frequently garbage. One of the results may be that inconsistencies are not picked up by technicians using Claim Digger as a primary means to analyse updates. Therefore, the schedule submittal may be approved, but it doesn't represent the planned approach to the work.

All of these baseline schedule issues can be fixed. But to do so, owners and contractors need to work together in the spirit of true project partnership to define the required level of detail in the project schedule. This includes allowing modification of the schedule midstream without penalising the contractor if the way to build the job can be optimised. It can also benefit the project if bidders include alternatives if there are different ways to build the job, and include sensitivity analyses. The contract could then be customised to the way the owner and the successful bidder agree the job will be built.

The project schedule should be a tool for contractor and owner to jointly manage and coordinate the job. Without a quality, approved schedule in place, changes cannot be addressed in a manner that is fair and reasonable to both parties. Ideally, the schedule provides enough information that contractor and owner can help each other succeed. ☺



As part of the Southeast Collector Trunk Sewer project a hanging system ensured a live 2.6m diameter sewer could be successfully bypassed. **Jordan Schreiner** and **Matthew Geary**, of Hatch, and **Stephen Marino**, of The Regional Municipality of York report



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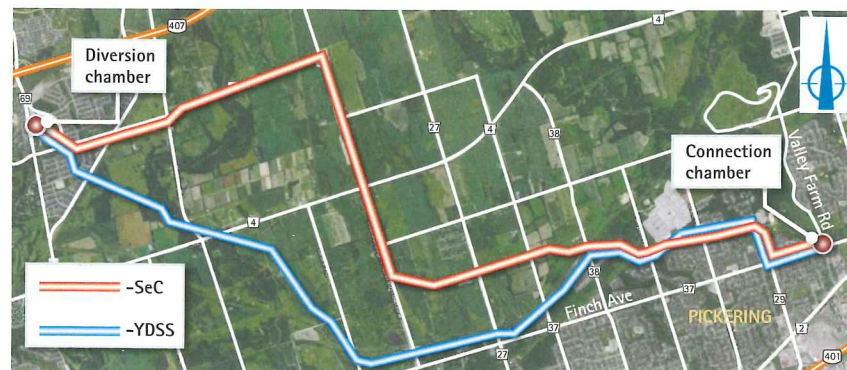
THE SOUTHEAST COLLECTOR (SEC) Trunk Sewer is a 15km-long, 3m-diameter wastewater tunnel designed by Hatch that twins an existing section of the 2.6m-diameter York-Durham Sewage System (YDSS) tunnel. Both tunnels are located north of the City of Toronto. The SEC provides capacity for the rapidly growing York Region population and supports development. Construction of the SEC allows the twinned section of the YDSS to be bypassed in order to clean, inspect and perform essential maintenance when required.

The project included construction of 19 shafts and chambers with depths ranging from 8 to 48m and seven facilities that support the operation and maintenance of the sewer. In 2011 the construction contract was awarded to Strabag for CAD 291M (USD 217M). Hatch and Aecom created a joint venture team to provide construction management services.

The YDSS tunnel was completed in 1979 and constructed using open-shielded TBM technology with ribs and lagging for temporary support. This was followed by installation of 380mm-thick unreinforced cast-in-place (CIP) concrete for the final lining. The YDSS sewer

Above: The YDSS hanging system installed at springline and SEC PCTL demolished within the connection chamber

Below: The SEC and YDSS tunnel alignments



system has many connections that collect flows from various urban areas within York Region. The section of the YDSS that was twinned by the SEC sewer flows under gravity conditions and is the main and critical connection between the upstream sewer systems and the downstream Duffin Creek Water Pollution Control Plant.

SOUTHEAST COLLECTOR TUNNEL

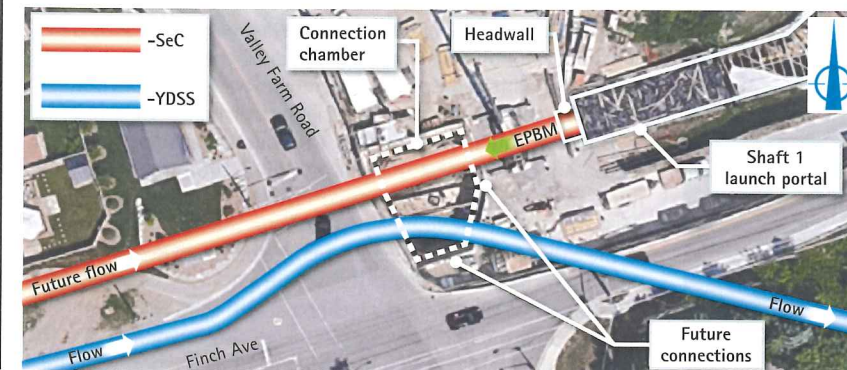
The SEC tunnelling was carried out by using four owner-procured Caterpillar Tunneling Canada 3.6m-diameter EPBMs, which utilized a single-pass, 200mm-thick, steel fibre-reinforced, six-segment universal precast concrete tunnel lining (PCTL). The EPBMs mined through full and mixed-face conditions consisting of plastic till, non-plastic till, silt, sand, cobbles and boulders with overburden depths ranging from 5 to 45m. While tunnelling, the EPBMs were required to operate with earth pressure balance pressures of up to 3.0bar.

Given the sewer's harsh operating environment and the minimum 100-year design life of the tunnel, special considerations for the PCTL were made. Steel fibre-reinforced concrete (SFRC) was utilized to ensure long-term structural durability in the event of section loss over prolonged exposure of the tunnel lining to hydrogen sulfide (H₂S). This was the first application of SFRC tunnel lining for York Region. In addition, the concrete mix specified very stringent permeability requirements to mitigate section loss due to the anticipated corrosive environment. Permeability tests incorporated the use of pressure cells and uniaxial water flow measurements under pressure across the concrete sample.

B2 TUNNEL DRIVE

The SEC tunnel is comprised of four distinct drives. Tunnel drive B2 was the easternmost drive and was the first to launch. The connection chamber lies at the eastern downstream terminus of

Below: An overview of the connection chamber



tunnel drive B2 where the YDSS and SEC flows combine back into the downstream portion of the YDSS tunnel. Tunnel drive B2 launched from shaft one and passed through the future SEC-YDSS connection chamber shortly thereafter; this drive encountered the most challenging and varied conditions of all four drives.

The EPBM and trailing gear was completely assembled prior to launch because the contractor was able to take advantage of the space provided by the launch portal configuration. The contractor decided to install the cutterhead with a full face of ripper tools. Immediately westwards after the connection chamber there were 850m of mining through fine sands and mixed-face clayey silts below the groundwater table with only 5 to 7m of ground cover beneath the busy road right-of-way of Finch Avenue. This presented extremely challenging conditions for settlement control. Settlement monitoring points were installed at a frequency of 10m. Average settlements were recorded as 15mm in this zone of the tunnel drive.

Upon break-out into the first service shaft of 14m ID (S2) the EPBM was turned 90 degrees and re-launched to the north under Liverpool Road and tunnelled for approximately 550m in similar

challenging ground conditions. This tunnel stretch finished when repairs to the EPBM cutterhead and cutting tools were undertaken within a pre-constructed emergency secant pile headwall. The headwall was installed after damaged ground conditioning system lines within the EPBM cutterhead chamber were identified. The headwall served as a safe haven for the repairs.

With repairs completed over the course of approximately four days, drive B2 then continued from the headwall and passed beneath the existing YDSS under live flows with 9m of ground cover and only 1.3m clearance between the EPBM and the bottom of the YDSS. Jet grouting around the YDSS invert in advance of the TBM passing to mitigate settlement induced by tunnelling. A maximum of 2mm settlement was registered on the YDSS. (To read more about the grout programme see *Tunnels & Tunnelling North America*, August 2015, page 34.)

Approximately 50m past the YDSS crossing the EPBM crossed under a watercourse at shallow cover of only 6m. During this section the upper EPB target pressure limits were watched carefully and environmental controls were on-site to mitigate any frac-out incidents that could have occurred.

After passing beneath the watercourse the EPBM tunnelled 700m through primarily full-face sandy silt till conditions before reaching a pre-installed freeze block utilised as an entrance block for maintenance shaft one. Mining through the frozen ground proved to be challenging as it was discovered early on that the ripper tools were severely worn. The EPBM, however, eventually broke-out into the shaft with minimal groundwater inflow. Once the replacement of all the cutterhead tools, as well as the inspection and maintenance of the ground conditioning system and trailing shield brushes, was finished the EPBM

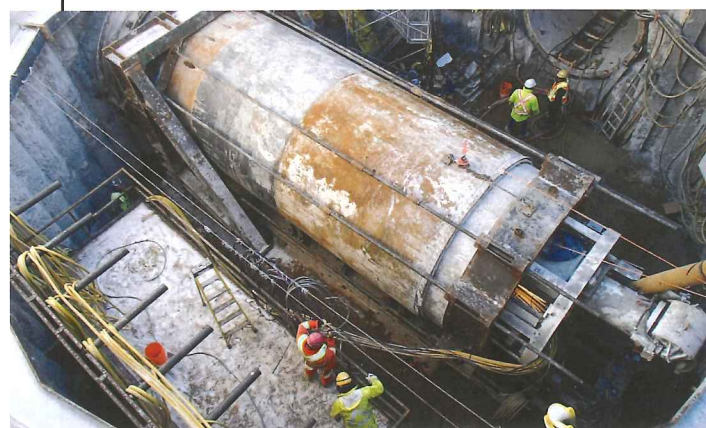
Procurement

York Region implemented advanced procurement of the TBMs and lining system to introduce critical schedule acceleration for the project, while also allowing the project team to stipulate and implement EPBM features considered essential to ensure a high standard of quality for the project investments. Based upon York Region's previous project experience with EPBMs, challenges were faced with material ingress through the TBM trailing shield across the tail seal brushes. Innovations integrated on the SEC EPBMs included:

- Four independent rows of tail seal brushes to mitigate potential ingress of material from the back of the trailing shield
- An inflatable 'emergency seal' integrated on the trailing shield adjacent to the row of tail seal brushes closest to the front of the machine, with the ability of a one-time use to seal off material inflow in the event of an uncontrolled failure of the tail seal brush system
- Tailshield annulus grouting system – the first known application of this method of grouting on a sewer tunnel in Canada, comprised of grout pipes integrated around the trailing shield and a two-component grout mix with fast-setting gel time to minimize potential settlement impacts. The two grout components (A/B) were combined at the discharge end of the injection nozzles at the end of the trailing shield with grout injection programmed to be simultaneous with mining advance

The cutterhead design included provisions for back-loaded interchangeable disc cutters and ripper teeth excavation tools. The cutting tool dressing arrangement for the cutterhead was the responsibility of the contractor.

Below: TBM breakthrough in shaft 2



continued mining the final 750m of the 2.9km drive through a complete range of glacial till conditions with depths of cover ranging from 20 up to 30m.

Upon completion of tunnel drive B2, construction of the connection chamber commenced and required the existing YDSS to be supported across the chamber by both a hanging system and a cradle, and bypassed using a hydraulically-extensible steel flume. This allowed construction of the benching and final CIP chamber structure to be completed without disruption of flows within the YDSS. Using the experience gained from the live bypass within the connection chamber this same operation was performed in the diversion chamber located at the western upstream portion of the SEC tunnel.

CONNECTION CHAMBER DESIGN

The connection chamber is the critical point in the sewage systems where flows of the SEC and YDSS combine and are conveyed directly to the Duffin Creek WPCP. The chamber incorporated sluice gates at all inlets/outlets allowing selective bypass of flows from either sewer coming into the chamber. It was paramount that all construction activities related to the chamber did not interrupt live flow conditions within the existing YDSS at any time.

Unreinforced knock-out panels were included in the final chamber wall design for potential future sewer connections and the rooftop structure incorporated precast concrete panels that are removable for sluice gate maintenance and access for future works. A combination of CIP concrete as well as custom-formed stainless steel was specified to facilitate curved benching profiles.

Hatch designers had specified the complex chamber excavation arrangement, hanging system of both the YDSS and flume bypass as well as the support of excavation in the contract documents. This decision helped mitigate the risk of interruption of the YDSS flow during chamber construction. A sequence of secant piles with embedded steel soldier piles was specified as the support of excavation to create a sealed shaft. Fibre-reinforced plastic (FRP) soldier piles were also integrated into the soft tunnel eyes of the chamber support of excavation walls for



Above: Demolishing the SEC final lining

the SEC tunnel. In addition to the secant piles, there were two levels of struts and walers included in the design, as well as steel hanging system used to support and hang the existing YDSS sewer and the flume bypass across the connection chamber excavation.

MONITORING PROGRAM

Due to the inability of a complete diversion of YDSS flows and the critical and complex sequencing of the construction, an extensive monitoring program was carried out that included a CCTV feed in the live sewer and an automatic and continuous precision monitoring system. The data for both systems were accessible online by all parties. The system used a robotic total station that measured Leica prism targets on a continuous basis at 15-minute intervals. The review and alert levels defined for the measured movement of the sewer were specified in the design and triggered automatic emails to key contacts upon exceedance. Vibrating wire strain gauges were also installed on the vertical rods of the hanging system.

CONSTRUCTION SEQUENCING

Prior to tunnelling, the section of the connection chamber perimeter secant pile wall for the SEC tunnel was installed, confirming a reliable annulus seal between the secant piles and SEC tunnel during passage of the TBM. A minimum clearance of 500mm was preserved between the existing YDSS and the secant piles. This led to "windows" of unsupported ground around the YDSS tunnel that were shotcreted once they were exposed during the excavation sequence.

Once the tunnel drive was completed, excavation of the connection chamber commenced. The chamber excavation proceeded to springline of the YDSS tunnel and allowed the erection and installation of the steel hanging system to take place. The contractor performed some coring and concrete testing of the YDSS final lining at this stage to confirm compressive strength and to verify the as-built lining thickness. The compressive strength of the concrete cores tested to 30 MPa and the YDSS tunnel lining thickness was determined to be

equal to or greater than the original design. The existing concrete was observed to be of good quality and did not have any visible deterioration due to time elapsed or exposure since installation.

Once the hanging system installation was completed, the precision monitoring system was installed, tested and baselined. The excavation then proceeded for the north end of the chamber, facilitating the demolition of the exposed SEC PCTL. Exposing the SEC within the connection chamber revealed continuous annulus grout and high-precision ring build, which confirmed TBM and inspection records.

Excavation then continued for the south end of the shaft from springline of the YDSS. The underside of the YDSS was exposed in increments of 2m across the length of the connection chamber. This allowed inspection of the existing steel rib where gaps were found at the invert ribs. New connecting plates were designed and welded on the ribs to ensure continuous support. The full span of the YDSS was eventually suspended 11m across the excavation by the hanging system. Settlement review levels were activated on two prisms at mid-span springline of the suspended sewer but showed no further movement upon full exposure of the YDSS and no other alarms were triggered. Excavation then proceeded to the base elevation and the final base slab was completed. During this phase a temporary concrete cradle was poured between the YDSS and the base. The cradle allowed for the removal of the YDSS hanging system, temporary walers/struts and pouring of two concrete wall lifts for the final chamber walls.

DESIGN AND INSTALLATION OF THE FLUME

Utilizing a flume was required to facilitate demolition of the existing YDSS tunnel within the chamber while maintaining

Below: The YDSS fully hanging across the connection chamber





Above: YDSS flume bypass retracted and lowered

flows across the chamber. When the flume was hanging it also provided the needed space to build the benching to channel flows through the chamber. The contractor was responsible for the design and manufacture of the flume. The contractor performed Lidar surveying to determine the interior dimensions of the YDSS. The design utilized a three-piece steel cylinder assembly and each end used hydraulic jacks to independently extend and retract using control switches. Custom, inflatable Multiflex seals were fabricated for the flume ends along with a secondary grease sealing system to seal off the annular gap between the flume and YDSS intrados that varied in depth. Continuous pressure was applied to the seals through an air supply system that included low-pressure warning sensors and backup generators.

On the day of the flume installation, pre-cut segments of the upper portion of the YDSS were removed by crane leaving the bottom half of the cradle-supported sewer and exposing live sewage flow. Once the upper half was removed, the retracted flume was lowered slowly into place, and the flume ends were extended and seals inflated. The flume achieved all functional requirements with practically no detectable seepage. A steel hanging system was installed to hang the flume, and the temporary cradle and remaining half of the YDSS were demolished and removed.


Implementing the hanging system for the flume permitted the installation of the final benching and sluice gate to commence. Once finished, the flume hanging system was removed after the flume was supported from below with temporary steel legs. FRP service walkways and ladders were then installed and the precast concrete roof slabs placed, leaving a lifting window open for flume removal. The flume was removed by depressurizing the seals, retracting the ends and then finally lifted out

introducing live sewage flows into the connection chamber for the first time. Removal of the flume concluded the sewer bypass process and permitted the completion of the shaft roof and FRP platforms/ladders for the chamber.

In the event of a failure of the hanging system or bypass process a risk mitigation plan was established. Although they were not used, additional safety measures were implemented and equipment was mobilized and available at the work site as a precaution. Three high-powered cameras were also placed within the work site and chamber and provided continuous real-time footage available for mobile viewing.

CONCLUSION

Construction of the connection chamber provided a unique opportunity to uncover and compare tunnelling methods installed 35 years apart. The YDSS on the south of the connection chamber used traditional open-shielded TBM tunnelling with rib and lagging temporary support before a second pass of CIP unreinforced completed the final lining. While the SEC to the north used a sophisticated EPBM incorporating a single pass state-of-the-art PCTL. After uncovering the tunnels it was obvious that both the YDSS and SEC demonstrated characteristics of effective design and high quality construction. The effectiveness of EPBM technology was clear from the challenges faced and overcome on the B2 tunnel drive as it tunnelled through a range of conditions. Although open-shielded technology is suitable for tunnelling in more cohesive till materials, along with dewatering when necessary – EPBM technology is a proven system capable of handling the full range of glacial till ground conditions found in Southern Ontario providing exceptional settlement management without needing dewatering.

The connection chamber construction and YDSS bypass were successful with uninterrupted flows within the existing YDSS. These high-risk activities were determined early on in the design stage and led to prescriptive design and phasing for the work including well-defined expectations within the contract specifications for monitoring and contingency planning. The requirements of the contract were stringently applied during the undertaking, and the contractor's team was involved and dedicated to completing this sensitive part of the project without incident. Using the experience gained from the hanging and bypass operations at the construction chamber a similar exercise was executed successfully at the western terminus of the SEC tunnel in the diversion chamber. Successful collaboration and communication between the designer, owner, construction management team and contractor was crucial to the success of both the connection chamber construction and tunnelling efforts. 



Right: Flume hanging system installed

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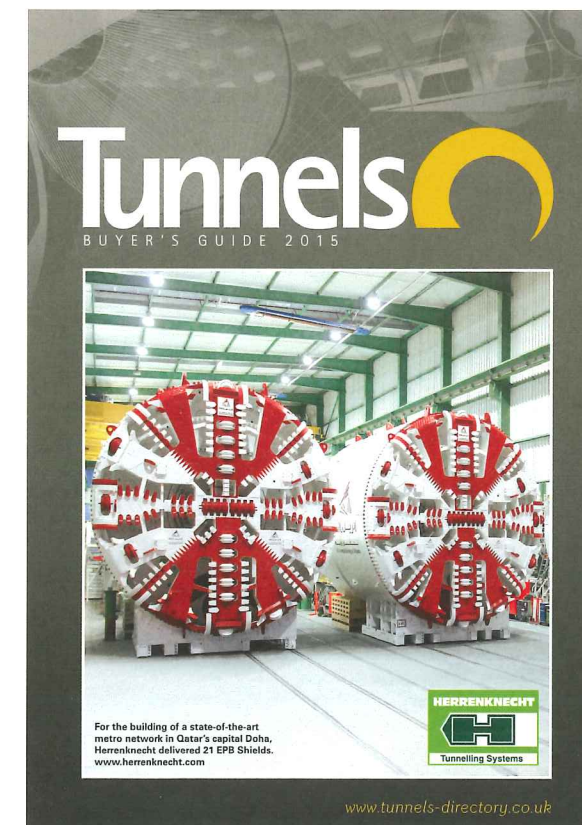
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CROSSRAIL'S SCL SHOWPIECE

C510, the biggest SCL contract for Crossrail, has included 1.5km of tunnels and the largest cavern on the new line. **Keren Fallwell** reports



Keren Fallwell

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



Above: The access shaft at Finsbury Circus

CROSSRAIL IS A PROJECT of superlatives and Contract C510 – early access shafts and SCL works for Whitechapel and Liverpool Street stations – has had its fair share.

The GBP 250M (USD 318.24M) contract, undertaken by BBMV, the joint venture comprising Balfour Beatty, BeMo Tunnelling, Morgan Sindall and Vinci Construction Grands

Projets, is the biggest SCL contract for Crossrail, in terms of both volume, with 1.5km of SCL tunnels, and value, and includes the biggest cavern on the new line.

C510 involved construction of the early access shafts and sprayed concrete lining works for both Whitechapel and Liverpool Street station tunnels. Works included the shafts and adits, platform tunnels, TBM reception chambers and launch chambers, cross passages, access passages, escalator barrels, ventilation ducts and a link passage from Crossrail Liverpool Street station to the London Underground Northern Line Moorgate station platforms. BBMV was also



Above: TBM "Elizabeth"



Left: Work at Whitechapel in January 2013

Right and Bottom right: Work at Whitechapel through 2013

the Whitechapel site to the east is in an urban area with residential properties, a school, supermarket and doctor's surgery in the vicinity. Both sites have presented challenges.

"Working on the two sites has almost been polar opposites," says Crossrail project manager Jules Boyd. "In Finsbury Circus, because of the proximity to a lot of businesses, we faced noise sensitivity during the day whereas at Whitechapel, which is more residential, it was more at night."

At Finsbury Circus deliveries were made around the clock but at Whitechapel they were restricted to 8am to 6pm. Also at Whitechapel, an acoustic shed was installed over the Brady Street construction shaft to reduce noise.

Whitechapel was also made more logistically challenging by being the only mined station without a central concourse.

"It meant everything had to go through two cross-passages off the shaft. It was one of our biggest headaches because it's more limiting but we managed it with timing and programmes," says BBMV project manager Peter Leyton.

Each site had its own batching plant to produce concrete and shotcrete and had sufficient space to store a weekend's production.

At Finsbury Circus, interfaces with existing tunnels also added to the complexity.

"The Hammersmith & City Underground line runs right through the centre of the site, in some places with just 600mm to 1m cover," says Leyton. "The Northern line comes up above our platform tunnel, but below the escalator, and the Post Office tunnel is just 800mm above our tunnel and only 1-2m away from the construction shaft."

The geology was predominantly London clay although in some areas terrace gravels were also encountered. The 30m-deep Whitechapel construction shaft was constructed with segmental lining through the initial layer of terrace gravels. Once it reached London clay it was grouted and then SCL applied to the full depth. The 42m-deep shaft at Finsbury Circus was constructed using the same principle.

The westbound cavern – the largest cavern on Crossrail – was



responsible for constructing three compensation grouting sites for Liverpool Street station and a compensation grouting shaft for the Whitechapel works.

BBMV handed over its Whitechapel works at Easter, while the Liverpool Street element of the contract is due for completion in August.

The nerve centre of the Liverpool Street works has been the 42m-deep access shaft in Finsbury Circus, a prestigious address in the heart of the City of London and home to several listed buildings. The jobsite sits on around three-quarters of the Grade II-listed gardens, formerly a bowling green, in the centre of the Circus, nestled up against the pavilion and seating area. In contrast,

created in a six-stage process using sidewall drift excavation.

"We created a teardrop shape then an invert teardrop shape, and did the same on the other side. We then took the crown out, leaving the side walls in position. We then took the crown section out all the way to the end, enlarging all the time," says Leyton. "The final process was to take out the side walls to the invert, then take out the side walls to complete the ring and the invert."

The TBM then came through and bored all the way from the end of the cavern through to Liverpool Street and a crossover was constructed to connect with the eastbound cavern.

At some of the other Elizabeth Line stations the pilot tunnels were bored by the TBM but, because of timing, at Liverpool Street and Whitechapel BBMV drove the pilot tunnels with SCL.

"The pilot tunnels were 6m in diameter and then the enlargement to full-size platform tunnels of 12m diameter," says Leyton. "They were progressed in three stages – 1m of excavation and sprayed lining, then advance another metre and sprayed lining, and then a 2m invert which completed the ring before moving on to the next advance."

Once the pilot tunnels were driven, dewatering could be carried out if necessary.

"We're largely in London clay for both stations but the interface between us and underlying layers was fairly close," says Boyd. "We installed depressurisation to draw water out and as we came to the enlargements we were depressurising ahead of ourselves before the main tunnels were complete."

The primary and secondary linings were applied using the Lasershell principle to improve safety. The method, created by Morgan Sindall and BeMo and first used in the construction of Heathrow Terminal 5, uses a back-hoe excavator to remove smooth scoops of ground from the working face. Its advance is continuous, but further ahead at the top than at the bottom – effectively an inclined face. The walls, crown and floor of the tunnel are lined with a coating of sprayed concrete as tunnelling advances. The geometry of this sprayed concrete lining is controlled with the aid of laser surveying.

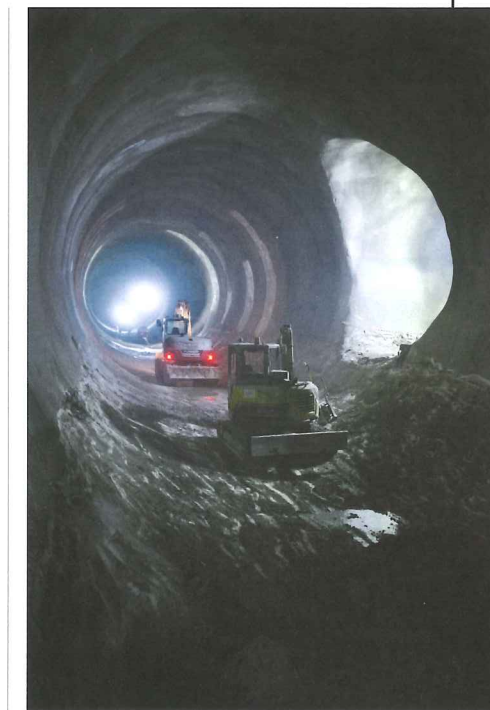


Above: Platform tunnel waterproofing lining works at Liverpool Street station

Right: Liverpool Street platform tunnels

Left: Work at Liverpool Street

Bottom left: Crew members walk in the tunnel near Finsbury Circus



Completion of the 'support ring' in a steady progression closely behind the face means that the excavator, concrete gun, and their operators, remain beneath the protective canopy of a completed portion of tunnel lining. The technique also improves ground stability.

"If you're going uphill using the traditional method you find yourself right underneath the excavation but with Lasershell it pushes it forward and with suspension it keeps the operation and machine away from the muck being excavated," says Leyton.

Boyd says the Lasershell method is just one of the significant advances he's seen in the industry.

"Laser theodolite profile control is one

of the most significant developments I've seen in tunnelling – it does away with the need for lattice girders and, together with shotcrete robots and steel fibres replacing weldmesh, takes people away from open ground," he says.

A large element of C510 was the control of ground movement and compensation grouting, which was carried out by Vinci Construction subsidiary Bachy Soletanche.

At Whitechapel the depth of the work meant the best solution was a fan of tubes à manchettes (TAMs), up to 63m, radiating from a shaft. At Liverpool Street the original plan was to sink shafts around Finsbury Circus but, to minimise disruption to the area, instead it was decided to drive two grout adits from the construction shaft and from there, TAMs were installed under all the surrounding buildings. This decision had unexpected benefits. "Because all the holes are drilled parallel it saved nearly 7.9km of drilling compared with fanning where a third of the hole is pointless because it's very close to the injection point," says Boyd.

Right: Finsbury Circus in October 2012



The results, which were reviewed on every shift, revealed about 80mm of controlled, rather than differential, movement around the Finsbury Circus shaft. "The difficult buildings were the likes of Britannic House. It has a retained façade from the original Edwin Lutyens design, which is easy and ground bearing, and a new piled structure at the back which behaves very differently," says Boyd.

One of the highest risk pieces of tunnelling was the top access passage that comes out of the Moorgate shaft. Here Bachy Soletanche carried out permeation grouting to cement together the river terrace deposits which lie directly above the London clay and above the escalator alignment. Once the permeation grouting was completed, Bachy Soletanche constructed a pipe arch above the crown of the tunnel to provide further support to the escalator tunnelling works.

"It was done in gravel so it was technically challenging," says Boyd. "There were two big permeation grouting phases requiring 1,000 holes and about 1,000m³ of grouting to consolidate the gravels." After discussions with the peer review board, a more traditional approach was added as part of the solution.

"When we first drilled away from the shaft diaphragm wall there was quite a lot of groundwater and sloppy sand so, together, we came up with the solution of doing dewatering and a traditional boxed timber heading for the first 12m," says Boyd. "First the steel pipe arch, or pipe umbrella, was drilled, which were 16m-long, thick-walled steel tubes at 300mm centres which defined the tunnel profile and offered support ahead of the advancing face. Then we did the timber heading. There was also the opportunity to do a bit of additional local dewatering from that if necessary, rather than open a large face."

At Whitechapel the tunnel alignment ran through the piles of a school so the building had to be pre-jacked to mitigate any differential settlement.

"We excavated under the school during the holidays and installed mini piles which avoided the tunnel profile," says Leyton. "They were capped and tied into the existing pile, then we installed jacks between the new beam and the existing foundations. Once the jack was installed we cut the existing pile along the top. As we tunnelled we took out the existing piles and controlled any movement in the school by jacking it in four separate jack locations."

Perhaps the biggest innovation for C510 was the solution developed to create the escalator barrels at Liverpool Street. Completion of the three 9m-diameter escalator barrels linking the platform level with the ticket halls was early in the programme but access to the top of the barrels was delayed because other contractors were still working in the ticket halls. It was a similar situation at Whitechapel where BBMV needed to start the pilot tunnel but access from the top was restricted

Left and Below: Work at Finsbury Circus in January 2013; and the grout shaft earlier, in February 2012



because the Durward Street shaft was still being constructed.

Rather than wait and create delays to the programme, the BBMV team decided to find a solution to excavate the 30 degree incline from the bottom up – safely.

"With traditional uphill excavation the excavator is placed on the invert and the team is below the excavated face. It can be managed but to mitigate any risks we had to look at a new system," says Leyton.

BBMV approached German company GTA which has been manufacturing suspended platforms and access ways for 40 years. The solution was an uphill excavator suspended from rails installed in the tunnel ceiling.

"They had produced mounted drill rigs, personnel carriers, boomers and suspended systems for the coal-mining industry in Europe but they had not done an inclined excavator," he says.

The unit is suspended from the ceiling on a rail system installed as the excavator progresses with the tunnel advance.

"The hangers are sprayed in and from the basket you advance the rails which the system hangs off," says Leyton. "Quite a lot of temporary works were required to install it but you're hanging 15t of equipment off it – and once it's installed it becomes part of the excavating process."

The machine has an excavating arm and a spraying arm, and a universal coupler so it could accommodate a man-riding basket or a drill rig.

The electric-powered excavator eliminated the emissions generated by traditional diesel-powered excavators.

A walkway along the side of the excavator provided access for the engineer and quality inspectors to view the machine and the works. It also served as an emergency escape route for the operator. The Lasershell principle was also applied to the excavator barrels.

The uphill excavator's rate of progress was slightly slower than traditional downhill excavation because of the need to install the hangers and check the temporary works but being able to start work before the ticket halls were complete saved time on the programme. "The benefit of this solution was taking the escalators off the critical path. It meant we didn't have to wait for the access shaft to be completed and all other systems were already up," says Leyton.

BBMV says the uphill excavator, which won the Technical Innovation of the Year award at the 2015 New Civil Engineer International Tunnelling and Underground Space Awards, enabled completion of the escalator tunnels six months ahead of schedule and saved GBP 13.5M (USD 17.20M) on general time-related costs. In addition it eliminated the large amount of temporary works that would have been required for downhill excavation.

It also, says Boyd, kept the C510 and C502 – the main

Left: Finsbury Circus shaft for Liverpool Street station and platform tunnels

construction contract for Liverpool Street station where Laing O'Rourke is the contractor – contracts apart as long as possible.

"One of the hardest things is to manage the interfaces between contractors. This was good because it kept 510 and 502 as separate contracts for as long as possible," he says.

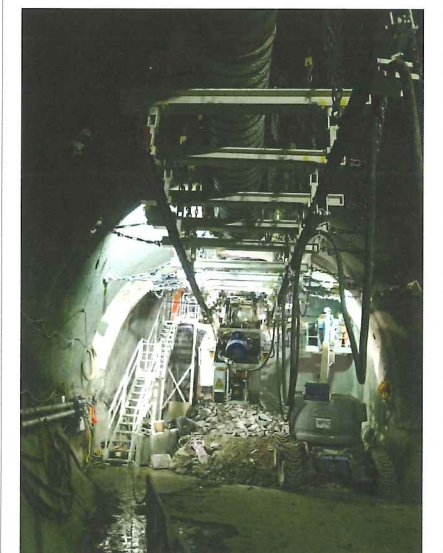
BBMV says downhill excavation will always be used where possible but this uphill method provides another solution to consider where necessary.

"It opens up another set of possibilities; it's another tool in a contractor's arsenal," says Boyd.

As with other developments throughout the contract, the uphill excavator was subject to review by an expert panel.

"It went through several iterations with the expert panel," says Boyd. "This is something new and novel so there's scepticism to overcome. That's a good thing because it makes everybody delve more deeply into the reasons and iron out a new process." 

Right and Below: A suspended uphill excavator was developed to create the escalator barrels



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TÅSEN UPGRADE

With 220 tunnels set for refurbishment by 2020, Norway is embarking upon a boom in upgrade work, and fire protection is a top priority



NORWAY'S TÅSEN TUNNEL, in Oslo is midway through an NOK 152M (USD 17.8M) refurbishment project that began in the summer of 2016 and is scheduled for completion this October. "The concrete walls of the tunnel are getting fire protected by means of prefabricated concrete elements and special fireboards. All emergency exits are being refurbished and rebuilt, and all technical installations are being replaced," explains Stein Olav Haugen, project manager for the main contractor Peab.

"The fire protection work is an essential part of the total fire protection system. Wall cladding shall withstand 120 minutes intensive fire without damaging the concrete underneath. Installation are closely controlled, there is a requirement of a maximum gap of 4mm in the joints, demanding of course a high precision installation," says Haugen.

To achieve this Peab turned to specialist fire protection contractor Firesafe AS, who says that this is just the start of a huge amount of work of this nature in Norway. "Norway is a special country with a lot of mountains and small cities around the country and we have a lot of tunnels. But now the government has put the money in and informed us that by 2020, 220 road tunnels have to be upgraded according to EU tunnel safety standard so it is a big market," explains Atle Killerud, technical manager for Firesafe.

For the Tåsen Tunnel the fire resistance had to be bolstered around the entrance and exit of the tunnel where the cover from the concrete to the steel reinforcement was considered inadequate to withstand a hydrocarbon related fire for more than two hours. This was not the case in the centre of the



Bernadette Ballantyne
Bernadette is an engineer and
freelance technical journalist



Above: Installing the boards requires three people plus the help of a scissor lift



tunnel, which was constructed using prefabricated concrete elements. As a result the first of the two tunnel sections required around 400m of additional fire protection around the tunnel walls at the entrance and a further 120m length along the exit. This is being applied in the form of PassiveTec tunnel liner fireboards made from fibre reinforced magnesium with other refractory products.

Firesafe selected the boards as an alternative to the more commonly used calcium silicate boards explaining that both systems offered the required fire protection but that the magnesium boards had other benefits. "The main advantage of magnesium oxide boards over calcium silicate boards is that they are water resistant," explains Chris Barry, contracts director at PFP Fire Systems, which owns PassiveTec in joint venture with SIG.

"A problem for tunnels is water ingress, water leaking into the tunnel can cause damage to boarding systems. The tolerance to water is much higher with magnesium oxide boards than with the calcium silicate," he says.

Water tolerance was particularly important here with the tunnel owners Norwegian governmental body Statens Vegvesen stipulating that the fireboards must be able to withstand an extensive

Above left: Fischer nail anchors with stainless steel heads fix the boards into the tunnel wall before the connections are sealed with PassiveTec XT intumescent sealant

Above centre: Concreting around the new electrical pit

Above right: Installing new electrical pits in existing concrete pavement

Below: The tunnel has been emptied from cars - ready for tonight's shift



cleaning regime of 10 cleans every year. So before Firesafe won the contract it had to prove that the magnesium oxide boards were up to the job. To do this the firm installed two boards at its warehouse and sprayed them at 200 bar of water pressure from a distance of 500mm. This was repeated 500 times to show that the fireboard could withstand the tunnel's cleaning regime. Before testing the two boards were first sprayed with a coating from Kapyfract AG. "The coating is a water based epoxy," explains Barry. "The paint has high water vapor permeability, protects the board from damage in the cleaning zone of the tunnel and protects the board and the tunnel from atmospheric pollutants in the tunnel. It is also a decorative coating with the colour matched to the customer specification," he says.


Installation of the boards was a three-person job involving two crews and a scissor lift. The 24mm thick, 1.2m wide boards were pre-cut in two lengths, either 1.15m or 1.6m and lifted into place before being secured using Fischer FNA II A4 anchors. The construction joints were sealed using the PassiveTec intumescent sealant. Firesafe targeted completion of a 150m² during each shift which could only be undertaken at night.

Both Peab and Firesafe point to this limited working window as being a key challenge for the project. During the weeks of summer 2016, the respective east - and then westbound path for a limited period were allowed to be fully closed for 24 hours per day. After this period the entire work in tunnels are only available for work during night hours. Traffic is redirected but has to be fully reestablished by 6am. This is very challenging and requires solid planning ahead," says Haugen.

As an important city centre connection the tunnel remains open to traffic until 10pm when the contractors can move in and begin their work but they only have around 7 hours.

As well as the fire protection Peab is refurbishing and rebuilding all emergency exits, and replacing the electrical installations. This makes for another difficult task as the system much be operational throughout the working day and can only be shut down at night. "All systems have to be fully operative every morning, before traffic is reintroduced to the tunnel," says Haugen who notes that the corrosive high traffic environment also means that high quality materials such as stainless steel must be used.

To date the works are progressing well. "We have done 50 per cent of the Tåsen tunnel and we start next week with the second lane, which is also 8000m². While we are doing this another tunnel in Oslo will start in July and we have offered our solution to that tunnel," says Killerud.

Of course with 220 tunnels to be upgraded these schemes are just the tip of the refurbishment iceberg and although not all of them need fireproofing, many do, ensuring Norway will remain a hot market for fire protection providers for the next five years. 

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CHANGE IT UP

Tunnelling projects require versatility especially with their associated space constraints, and excavators, with a variety of attachments, are important tools on site. The North American construction equipment show Conexpo was held in Las Vegas in March, **Nicole Robinson** explores some of the options available and new products that were launched



TEI

TEI Rock Drills and Brokk have been working together for more than five years to develop a drilling attachment that compliments their remote carriers along with the many other attachments available from Brokk. The newest product from TEI for underground construction is a high-torque drifter with a very short length, used on roof bolting rigs and allowing the use of percussion with only 448mm of length.

IN THE CONSTRICTED SPACE of an underground construction site the traditional approach of using task specific equipment has changed. Instead of having a machine sit idle in the mining process until required to be used again, any typical excavator with attachments can be used for several or all parts of the process.

"We are able to size an excavator to the job size, and attach a drill to begin the cycle," says Timothy Miller of Montabert. "Once blasting is performed, a bucket can be attached to perform the task of mucking out the shot. Once cleaned up, a breaker specifically designed for tunnelling and scaling can be attached, and final cleaning of the roof and ribs can be performed. The drill can

Above: A TEI drill working in a rail tunnel

once again be attached to install supports to maintain a competent opening."

This equipment is in demand at all stages of a project, even with a TBM doing the brunt of the excavation.

"A lot of traditional tunneling equipment is purpose built to do a single, specific task, and do it very well," says Chip Kogelmann of Alpine Equipment. "Roadheaders are an example of this. Their compact size and high power cutterheads generally

Nicole Robinson

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



Montabert

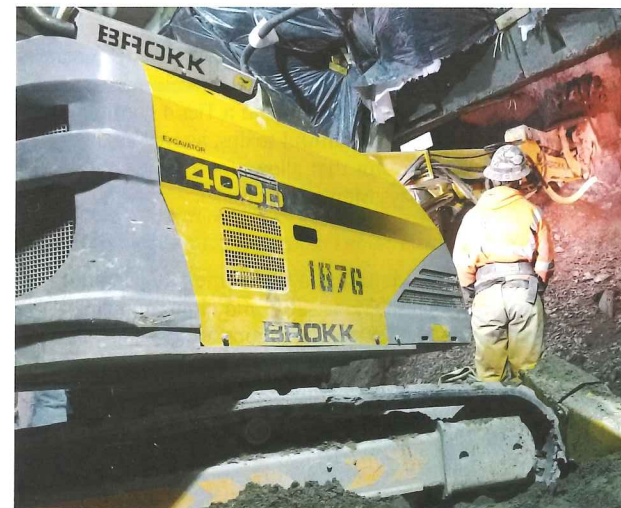
Montabert's new CPA 295 drill will be officially launched at ConExpo.

The excavator mounted rock drill attachment can be mounted on any excavator weighing more than 25t, does not require any major modifications to the machine. It also includes hydraulic dust control system, rod carousel and a radio remote control.

cannot be matched by an excavator. However, they are inflexible in terms of working range and use. What is best, of course, depends on the project."

Manufacturers widely report the ability to use multiple tools on one machine is driving demand for excavators and attachments. "Especially in the tunnelling industry this is helpful for smaller jobs and very limited access jobs," says Joe Patterson, vice president, TEI Rock Drills. "Of course the main production will always be jumbos or TBMs but those machines make a big mess and there needs to be auxiliary equipment to support these machines."

TEI supplies drills for remote carrier Brokk, which manufactures demolition robots mounted with a hydraulic breaker. "They can make short work of the tunnel wall when starting a cross-passage excavation," Peter Bigwood, Brokk's vice president of sales and marketing says. "Then, equipped with a bucket, they can excavate the material behind the wall. Where appropriate, they can be mounted with a drum cutter and grind away at softer materials like limestone. With a beam manipulator attachment, they can be used to lift and place the steel reinforcing ribs inside the cross-passage. Finally, a hydraulic rock drill integrated at the end of the arm can drill holes for rock reinforcement or even to prepare for ground freezing operations."



Above: Montabert's CPA 295 attachment

Left: A Brokk machine working on a tunnel cross section

Brokk

Brokk has recently introduced its 2,700 pound (1,224kg) diesel-powered demolition robot, the B120D. The new machine measures 31 inches (78.74cm) wide, with a reach close to 13ft (3.9m).

Brokk says it accepts the same range of attachments as its electric-powered sibling, the B100 and suggests its use in confined space work sites.

Compact excavators are necessary for shaft work, and Matthew Hendry, product consultant for Deere and Hitachi Excavators, explains for smaller diameters they offer four Zaxis models that have a standard boom configuration "with the ability to retract the boom and swing full circle largely within the width of the machine."

The Hitachi compact excavators have independent swing booms that allow the machines to dig parallel to walls on both sides of the machine. Auxiliary hydraulics with proportional control allow the excavators to handle a variety of attachments to assist in tunnelling, shaft, cross passage, stub outs and access drifts; hydraulic hammers and rotary rock cutters, for example.

He describes the control valve on Hitachi excavators "that evenly divides the available hydraulic oil to the number of functions the operator is demanding.

"What this means for the operator is a fast, strong, smooth excavator that is predictable and productive.

"For work in very tight conditions Hitachi compacts use the same control valve design as the larger machines,

Alpine

Alpine-rockwheel has developed special heavy duty versions of the standard Rockwheels specifically for the mining, tunneling, and underground markets. These feature job specific drum lacing, integrated water sprays, reinforced housing and internal safety valves to protect the hydraulic system.

providing precise predictable control. Our Zaxis 17U is a 1.7t machine that is only 38ft [11.6m] wide and can access very tight work areas."

Alpine's Kogelmann advises where there are workspace limitations underground configurations such as boom mounting the rockwheel instead of traditional stick mounting drastically reduce the minimum working height, and the use of zero-tail swing excavators minimize width.

There are special tunnelling excavators that feature short booms and tilting consoles such as Schaeff and Liebherr offer, and another special excavator-like machine is the line of ITC tunnel heading and mucking machines.

"The ITC machines have the capability of excavators but with through-conveyors for mucking or removal of material from



Above: An Alpine Rockwheel model D30 (110-kW) installed on a CAT320 excavator

Below: Hitachi's ZX75US-5 excavator



Hitachi

Hitachi offers four reduced tail swing (RTS) construction class excavators and six RTS compact excavators. These ten machines range in weight from 1.7 to 24.5 metric tons. Reduced tail swing excavators allow operators to work in tight conditions without the worry of hitting the counterweight while swinging the machine.

the tunnel face," Kogelmann explains.

Other enhancements to today's excavators include increased fuel efficiency, says Aaron Kleingartner, Doosan sales and marketing development manager. This is achieved with features such as auto shutdown. "Doosan excavator operators can configure the idle time from three minutes to 60 minutes," he says. "When enabled, the feature will shut down the excavator's engine when the preset idle time is met."

Doosan excavator operators can choose from four power modes for more control to better balance fuel consumption and machine power to the working conditions.

Manufacturer Takeuchi currently offers a diesel electric excavator, the TB216H (Hybrid), a 4,300-pound (1,950kg) machine featuring a 14.9 HP (11.11kW) diesel engine and 14.2 HP (10.59kW) electric motor. Each power source features a separate pump group, so performance is the same in either mode and the operational controls for each are identical. To operate in electric mode the machine can be tethered to a remote generator that can provide 400-480 volts.

"Modern excavators are all available in a Tier 4 configuration, allowing for low exposure to harmful toxins, as well as the enclosed cab of the excavator that allows for a more controlled operator environment, says Montabert's Miller.

ATTACHMENTS

An excavator should be viewed as a tool carrier, Kogelmann explains. It is an exceptionally-versatile and highly-mobile base machine that can be equipped with various attachments, and with quick change couplers the various tools can be exchanged rapidly in response to varying ground conditions or tasks.

"For example, in mixed ground a ripping bucket may be the most effective tool in soft to medium strength soil but when rock is encountered, the bucket can be quickly exchanged for a rockwheel cutterhead or hammer.

"Couplers such as those from Oilquick eliminate the need to manually connect hydraulic lines which saves a lot of time and eliminates the risk of contaminating hydraulic systems. There are also tilting and rotating couplers, for example Rototop and RotoTilt, that are like a human wrist and provide mechanical dexterity allowing the tool to reach just about any position. Cutting an arched profile is one example of when this would be useful."

Regarding attachments, rotary cutterheads (commonly known as rockwheels, cutterheads, or drumcutters) are becoming increasingly popular, reports Kogelmann. These attachments are

available for carriers of any size class and are widely available, even on a rental basis.

For underground construction these cutterheads are applicable for scaling after drill-and-blast, profiling rock, milling shotcrete, trenching for utilities or water control, tunnel advancing, tunnel notching or enlarging, especially in rail tunnels, he notes, and maintenance of floors and roofs.

Montabert makes attachments that convert excavators into rock drills. It is launching a new, mounted rock drill attachment at Conexpo, which aims to match or exceed the production rate of conventional drill rigs currently in the market. It has options to drill holes from 2.5 inches to 4 inches (63.5 to 102mm) in diameter, up to 72ft (22m) deep. General manager Stephane Giroudon says the new drill fills a void in the market. "Before the CPA 295, growing demand and cost concerns were calling for bigger drilling attachments with larger hole diameter and depth options, at greater speeds. This attachment's versatility and capability meet those needs."

Founded in Italy in 2001, MB Crusher manufacturers



Above: A bucket attachment from MB crushers

Left: A Doosan DX225LC excavator



Doosan

Additional enhancements include increased visibility from the excavator cab; operators have access to a 7-inch LCD screen to monitor the excavator's parameters while viewing a rearview or sideview camera image. In addition, critical machine data appears next to the camera view.

Below: Takeuchi's TB216H excavator



MB Crushers

Bucket attachments reduce the use of heavy-duty mechanical vehicles and the number of operators, and allow the reuse of demolition materials directly on site, reducing transport.

attachments, among them a bucket crusher that allows contractors to crush material inside the bucket. CEO Max Ravazzolo of MB America explains, "our machines allows anyone actually reduce in size any material—concrete, reinforced concrete, rocks, bricks, pavers, any man made or natural product—to improve the efficiency of transportation or to reuse it in place."

The attachments have been used in mining projects to reduce the size of blasted material to improve the load factor of the dumpers. They can reduce the number of trips through the normal crusher, he explains, because instead of feeding it with oversized rocks, the bucket reduces the sizes directly.

Takeuchi

Recently launched, the TB216H (pictured) has a dig depth of 7ft 10in (2.3m) and maximum reach of 13ft 5in (4.1m). Takeuchi says since the TB216H can be run emissions free in electric mode and due to its compact dimensions it would be well-suited for underground applications so long as the power source is no more than 1,250ft (381m) from the machine. It can be equipped with a thumb or small breaker.

THE WAR UNDERGROUND

The February meeting of the BTS Young Members hosted David Hedges, Bruce Simpson and Alan Thomas of the Durand Group who lectured on underground operations during the First World War and the resulting unexploded ordnance that plagues tunnellers to this day



Alex Backhouse
Alex works for Atkins and was rapporteur for this meeting



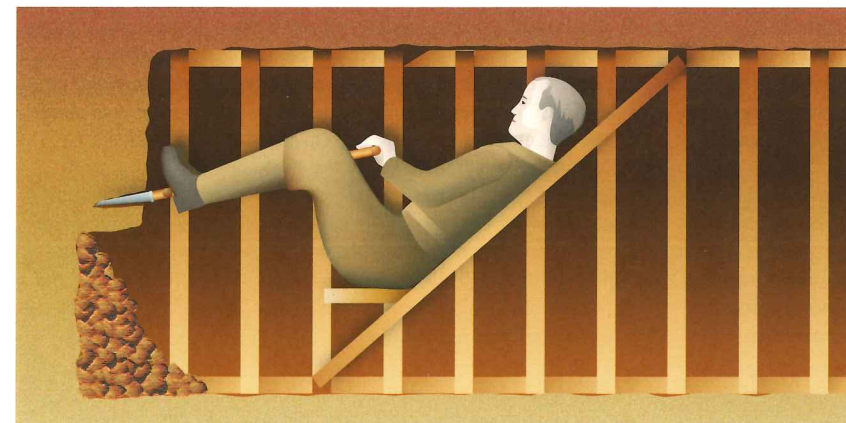
"GENTLEMEN, WE MAY NOT make history tomorrow, but we shall certainly change the geography," remarked general Sir Charles Harington to reporters on the evening of the 6th June 1917, prior to the Battle of Messines. And change the geography they did. The next day, the combined explosion of 19 mines marked the start of the battle, killing 10,000 German troops, and to this day is one of the largest non-nuclear explosions of all time. A century later the pockmarks of mine craters can be seen across France, and the war's lethal legacy lingers on.

It is estimated that up to 63M artillery shells, grenades and mortar rounds still lie unexploded across the Western Front. At least a quarter of these are suspected to be chemical. Every year around 10 people are killed by unexploded World War One (WW1) ordnance, of which a disproportionately large number are farmers. Adding to this deadly arsenal, as many as 100 old WW1 mines may be lying dormant under the old battlefields, lost in

Above: Concrete fortification destroyed by a tunnelled explosives cache. Such structures could be several metres underground



Above: The Lettenberg Bunkers on the Kemmelberg were built between April and May 1917 by the British Royal Engineers 175th Tunnelling Company. The five bunkers comprise a battalion headquarters, regimental aid post and troop accommodation beneath one of the most important observation view points from 1914, especially for the Messines Campaign of 1917. The bunkers are constructed of reinforced concrete poured in rough gravel on "elephant plates" - corrugated plates. Each bunker has an entrance and a window.



Above: Clay kicking, a tunnelling technique unique to the northwest of England found application in the trenches

THE DURAND GROUP

In February, the audience at the Institute of Civil Engineers were treated to a fascinating talk by the Durand Group on an aspect of warfare that is not often spoken about, tunnelling in WW1.

The origins of the Durand Group can be traced to 1988, when Canadian authorities asked the British government for assistance to identify a potential cache of wartime explosives. Twenty meters below the Vimy Ridge Memorial Site, France, lies the "La Follie" tunnel system. An investigation was led by British Army royal engineer, Phillip Robinson searching for old WW1 mines. During the investigation, 6000lb of high explosive ammonal (a combination of ammonium nitrate and aluminium powder) was found. It was the "Durand" mine.

Eight years later Robinson returned to Vimy Ridge and after further investigation identified another, larger, unexploded mine that lay dangerously close to a road junction within the

Memorial Site. This time the concern was that vibrations of the buses transporting visitors to the site could cause the 20,000lb charge, "The Broadmarsh," to detonate.

After successfully dealing with "The Broadmarsh," their experiences in the tunnels led to the proposal that they should continue the work. The Durand Group is now an eclectic mix of archaeologists, civil engineers, surveyors, bomb disposal experts, historians, military servicemen and even two fully qualified doctors. Together they investigate and preserve subterranean military systems, with the specific purpose to locate and diffuse unexploded war time ordnance.

THE START OF BRITISH WAR TIME TUNNELLING

Throughout the history of warfare, generally, the advantage has rested with the attacker, better able to dictate and manoeuvre the enemy into an engagement on its terms. However, for two long years between 1914-1916 no such advantage was to be found as the war stagnated, battle lines were drawn, and trenches were dug stretching from the North Sea to Switzerland.

As static warfare prevailed neither side could go forward, the only way left to them was down. Military engineers tried to break the stale mate by tunnelling under the enemy's trenches and detonating large mines. The hope was that such an explosion would destroy or damage the enemy's defences and an attack could then be launched against the weakened line capitalising on the ensuing chaos. The Germans were the first to practice this tactic. On December 15,

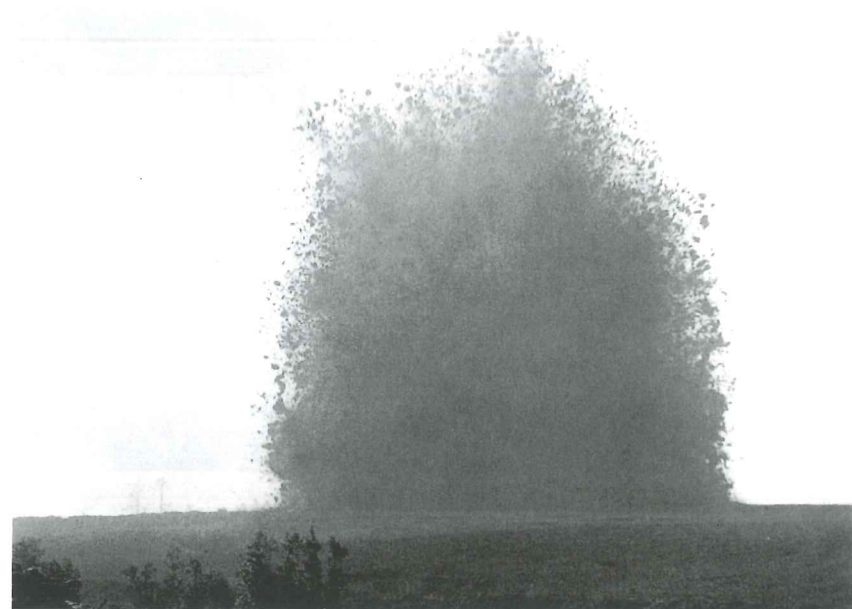


Right: Preserved World War 1 fighting tunnel in Vimy sector



1914, they detonated a series of mines under British trenches and used shallow tunnels to move troops safely across no man's land with considerable success. At the time the British had no response.

This was when the heavily moustached Conservative MP, engineer and soldier, John Norton-Griffiths heard of the difficulties the Allies were having tunnelling in the soft ground of Flanders. He was working on a sewerage renewal contract in Manchester and Liverpool at the time. The men who were working with him used a tunnelling technique known as 'clay kicking,' well suited to tunnelling small diameter clay tunnels, ideal for the Flanders clay. A single man would rest his back against a wooden frame (the cross) and using his feet push the spade into the face to remove a section of the soil. The soil would then be passed overhead to another miner for disposal. Norton-Griffiths believed that his 'moles' could be the answer and that the ground in France was actually very favourable for tunnelling and so wrote to the War Office early in December about his idea.



Above left and below: Images taken from within the tunnels when the Durand Group has explored the tunnel system

Above Right: Through its work the Durand Group hopes to avoid accidental detonation

It wasn't until several further successful German attacks using mines that his letter surfaced and on February 12, 1915, he received a telegram with orders to report to the War Office where he was swiftly escorted to the private office of secretary of state for War, field marshal Herbert Kitchener. Norton-Griffiths' response to the latest dispatches about the enemy's tunnelling operations and their effectiveness was to pick up the coal shovel by the fire and demonstrate the clay kicking technique.

Kitchener was impressed by the lively demonstration and dispatched Norton-Griffiths to France to ensure the viability of his proposal. Upon returning to Britain a week later, buoyed by a successful trip he proposed the swift formation of civilian miners to start without any formal military training. By the end of the month 18 of Norton's moles were in France, founding the 170th Tunnelling Company.

TUNNELLING

The moles helped create the vast subterranean labyrinth of running and fighting tunnels through the clay and chalk of the Western Front. Unlike tunnelling in the clay, chalk proved an ideal material tunnelling, self-supporting unless highly fractured and easy to tunnel through. This meant the most dangerous time excavating a tunnel was in the first 3-5m where the chalk was weathered and damaged by shell fire. Clay, on the other hand, was a different story. The British used the minimum amount of materials when propping the tunnels to increase speed and reduce the material requirements. However, in clay considerable support using timber and sometimes steel girders was necessary as the clay relaxed and expanded, increasing the pressure on the tunnel supports.

Typically, teams of four would be working the tunnel face at any one time, plus two men in support, removing spoil, preparing timbers and pumping air. The British favoured tunnels that were approximately 1.5m high and 0.8m wide. For every foot run in a subway tunnel 70 sandbags needed to be filled with the material. Disposing of the spoil presented a strategic problem.

If the enemy could see the large amount of spoil they would be notified of the allies tunnelling efforts and set up counter measures. Spoil was usually disposed of in artillery craters.

The subways enabled men to move unseen and protected offering significant tactical advantage. These tended to be



Above: The Pool of Peace (or Lone Tree Crater) in Wijtschate is now a peaceful reminder of the great Mine Battle of June 1917. The opening of the offensive was marked by the detonation of 19 deep mines under the German lines between Ploegsteert and Hill 60. The explosions formed enormous craters in the landscape. The largest and most impressive crater is the Pool of Peace. It is 12m deep and has a diameter of 129m



shallow, around 8m underground and deep enough to be impervious to shell fire. Below these the deeper fighting tunnels that were used to detonate mines passed through no man's land, typically just above the water table. Tunnelling close to the water table gave advantage to the diggers as it was significantly harder for the enemy to go underneath them.

In this claustrophobic environment, noise was the miner's constant enemy. Each side had listening tunnels, engaged in a blindfolded game of cat and mouse with men listening for enemy activity around the clock.

The objective of these tunnels was to determine enemy activity and if such a tunnel was discovered, to plant a counter

Above: Lochnagar Crater, Ovillers-la-Boisselle

charge (camouflet) and detonate it to destroy the enemy's tunnel.

Cases were also reported of where two tunnels would meet and furious fighting would ensue. For those working in the tunnels hand to hand combat, death by cave in and gas poisoning were common occurrences.

At the war's height 100,000 men were underground, employed in tunnelling activities. This hive of activity led to the creation of several hundred miles of tunnels of which some were used to plant mines under the enemy's lines. Mines became synonymous with large scale military operations. The month of June 1916 marked the peak of mine warfare in WW1. A total of 227 mines were detonated, equalling one mine every three hours. These skills came at a premium and miners could earn three times soldier's pay and those that had skills in mining were quickly poached from the army's ranks.

However, the use of mines was not the quick solution to the paralysis of trench warfare for which people had hoped. Despite the chaos of the mine explosions, the Germans quickly became skilled at using the resulting crater as a defensive stricture. The crater provided an incline for the attackers to assail and cover for the defenders to fire upon the advancing enemy. The proximity of the two armies' trenches also limited the size of the explosives used.

In short, tunnelling and the use of mines never proved to be the decisive technology that turned the tide of the war. In spring 1917 a series of grand offensives, the Battles of Arras, Messines and Passchendaele helped break the stasis

of the Western Front. The static conditions that had given rise to mining changed, largely concluding the major offensive and defensive mining operations. That is not to say mining held no part in the remainder of the war effort.

Tunnellers instead turned their expertise on creating safe dug outs for troops' accommodation.

EXPLORING THE TUNNELS

Before the Durand Group can investigate the tunnel system they need to find it. Often this involves an intense research exercise, sifting through old historical documents such as war diaries, intelligence reports and mining records. First-hand information from locals has proved invaluable in some cases, for example once this information came in the form of two men describing an old shaft that they used to slide down in an old oil drum until it got stuck and blocked the shaft. Since then the shaft had been buried and lost. Some weeks later with the tunnel system rediscovered the Durand Group found an old oil drum jammed in one of the shafts.

The Durand Group aim to maximise the archaeological benefit from their investigation, therefore each case requires attention to detail, recording and mapping of the tunnel system. The need to accurately record and map the surface and underground areas is key. They use multiple non-invasive ground investigative techniques such as ground penetrating radar (GPR), digital mapping and electromagnetic induction survey. Accurately locating subterranean structures is important, care must be taken to minimise the risk of damaging important historical artefacts and there is the risk of hitting unexploded ordinance. The group also use a pioneering 'endoscope' which involves boring a small gauge hole into the mine shaft and inserting a camera down the hole helping to unobtrusively investigate sections of the tunnel system.

Subterranean exploration is at the heart of the Durand Group's activity. A recent excavation in the Vimy site, was a gargantuan task--26 tonnes of chalk spoil, bagged and bucketed by hand was removed to access the site through an abandoned winch chamber. By its nature, the investigation of old war tunnels runs the risk of encountering biological contaminants, cave ins and explosive munitions.

Sadly, the Group first had experience of the dangers involved with tunnel exploration when in 1998 Mike Watkinson was killed when a section of

Questions from the floor

Alan Skada, BFK: where has your drive and passion come from?
Bruce Simpson: the excitement and experience of finding unique and incredible forgotten wartime relics. There is something special about breaking into a new system and opening up a forgotten time capsule.
Alan Thomas: for me it was because a close friend was killed in a tunnelling accident. After visiting his memorial, I got the bug for tunnel exploration and have never looked back.
Scott O'Neil, Miner: I saw the Durand Group being featured on the Discovery channel and was very interested in your work which is why I am here tonight. Is there an equivalent group for the other combatant nations?
Bruce Simpson: there is a German group in the Argon working at the site of the Battle of Verquor. The Germans and French arrived at the same time at the small mountain village at the peak and the fighting that ensued levelled the peak to a small flat plateau. They are finding lots of relics from the war there.
Ian Lee, Ex tunneller: did the British use any specialist plant to help them mine?
David: they struggled to use any plant due to the noise. They did try and used a mechanical boring machine in Belgium but it sunk and got stuck in the clay. It is yet to be found.
John Austin, OTB Engineering: how much were the tunnellers paid?
David Hedges: the British promised 3 shillings a day to the miners compared to the 1 shilling a day of soldier's pay.
John Remash: have you considered using drones to remote detonate the mines?
Alan Thomas: the Royal Engineers donated a drilling that was used for 10 years until it failed due to fatigue. However, no use of remote detonation modes are currently being considered.

clay sheared off in the "La Folie" system. As the Durand Group has continued their work their expertise in dealing with munitions differentiates it from others working in the field. To date they have made safe three mines equalling 16,000lbs of high explosives and explored three main WW1 tunnel systems.

The Durand Group's current work is focused on 'Engineering the Loos Salient 1915-2018'. It is an ongoing, inter-disciplinary study of the Loos battlefield. The Battle of Loos was the largest battle involving the British on the Western Front in 1915. The battle also marked the first-time poison gas was used by the British and the first major engagement involving Kitchener's all-volunteer army. The battle was also the third time the specialist royal engineer tunnelling companies used fighting tunnels to plant mines under the German to be detonated at zero hour.

The group hopes that when they are finished they can open some of the tunnels to the public for the first time.

Below: German trench destroyed by a mine explosion



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

ICTUS 2017

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

Shotcrete for Underground Support XIII

3-6 September 2017
Irsee, Germany
SUS XIII aims to pool the consolidated efforts from engineers, researchers and project managers from across the world in order to share and update state-of-the-art technology and best practices in rock engineering, rock support methods, TBM tunneling and deep excavation.
www.engconf.org

International Symposium on Aerodynamics, Ventilation & Fire in Tunnels (ISAVFT 2017)

13-15 September 2017
Lyon, France
Tunnel ventilation is a small part of the cost of a tunnel, however, it is often crucial for sizing the civil engineering works, and in allowing a given type of traffic. There is pressure upon designers and engineers to develop more cost-effective solutions for tunnel construction without compromising safety. This has been the premier international event to discuss new research and developments.
www.bhrgroup.com

Underground Infrastructure of Urban Areas

24-26 October 2017
Wroclaw, Poland
This ITA endorsed conference is being organised by Wroclaw University and the Polish Tunnelling Group. The conference will cover the theme: "discussion on problems related to underground Infrastructure".
www.pbp-ita.pl/

TBM Digs

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

12th Iranian Tunnelling Conference: Tunnelling and Climate Change

27-29 November 2017
Tehran, Iran
Drop in total precipitation around the world, especially in the Middle East and Iran has resulted in rapid decline of water resources. Water conveyance tunnels by transferring water from water-rich regions to arid regions can have a significant role in reducing consequences of this phenomenon. In some countries climate change has given rise to precipitation and has caused massive floods. In these countries drainage systems and water conveyance tunnels can have an important role in mitigating negative effects of flooding and climate change. Iran recently approached the highest temperature ever recorded on the planet, and is an ideal location for this conference theme.
www.itc2017.ir

Stuva Expo 2017

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

2018

NASTT No Dig 2018

25-29 March 2018
Palm Springs, USA
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www.nastt.org

World Tunnel Congress 2018

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

North American Tunnelling Conference

24-27 June 2018
Washington D.C., USA
The NAT is the premier biannual tunneling event for North America, bringing together the brightest minds in the tunneling industry.
www.natconference.com

11th International Conference on Geosynthetics

16-21 September 2018
Seoul, South Korea
The technical program will include a Giroud lecture, 5-6 plenary lectures (special lectures), 2-3 short courses and approximately 50 parallel sessions.
www.11icg-seoul.org

PIARC International Conference on Road Tunnel Operations and Safety

3-5 October 2018
Lyon, France
This World Road Association endorsed event comes amidst increasing interest in the emergence of new types of vehicles in the driving environment, and how tunnels will keep pace with continuing technological advances.
www.piarc.org

10th Asian Rock Mechanics Symposium

29 October-3 November 2018
Singapore
Asia is witnessing the greatest growth and demand in the world for infrastructure and resource development. According to Asian Development Bank, approximately US\$8 trillion needs to be invested in overall national infrastructure before 2020, 68% of which is for new capacity. Certainly, rock mechanics and rock engineering will have a critical role to play in many of these infrastructure and resource development projects. The theme for ARMS 10 is "Rock Mechanics in Infrastructure and Resource Development".
www.arms10.org

2019

World Tunnel Congress 2019

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

ECSMGE 2019

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

World Road Congress

6-10 October 2019
Abu Dhabi, UAE
The World Road Congress will cover a number of areas, including Road policies, Environment, Economics, financing, Governance of authorities, Planning, Risk management and many more.
www.piarcabudhabi2019.org

The British Tunnelling Society

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

BTSYM: Challenges in the drilling and blasting method at the main access tunnel for the Uma Oya Project

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

High Speed Railway Tunnel Projects & General Tunnelling Status in China

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

Finsbury Park Squareworks

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

Waterview Tunnel, New Zealand

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

Tunnel Design Life of 120 years - Definition, Assessment and Improvement

18 January 2018
The first meeting of 2018 will focus on design life requirements of tunnels and how these are assessed by designers; and improvements and cost savings that can be made on projects when the concrete mixes are tested early on in the design stage.
Speakers: Charles Allen, Phil Bamforth, Jon Knights

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

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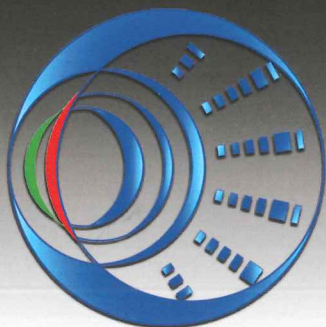
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