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Tunnels AND TUNNELLING

OUR METRO

TBM breakthrough in Bangalore marks the end of phase one tunnelling on Namma Metro – "our metro"

Diversions • ITA • Iceland

DOHA DONE

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

AT 10.44 AM ON 25 SEPTEMBER the last of 76 breakthroughs took place on the Doha Metro. The 7m TBM pierced the target wall marking the end of 111km of tunnelling for the Qatari capital. The incredible feat took 26 months and employed 21 TBMs to add up to 2.5km of new tunnel per week.

The scheme, which was recognised with a Guinness World Record for most consecutive TBMs in operation on a tunnelling project, is seen as one of the most logistically demanding in modern times.

Martin Herrenknecht, whose company supplied all of the machines, said of the achievement: "The world has never seen such performance. What Qatar Rail and our contractors in Doha have accomplished in just 26 months of construction time with the highest standards of performance, safety and quality is an absolutely Olympic achievement in modern infrastructure development."

A breakthrough ceremony saw around 200 guests, including political figures such as the Qatari Prime Minister and Minister of the Interior Sheikh Abdullah bin Nasser bin Khalifa al Thani, the Minister of Transport and Communication of Qatar Jassim Saif Ahmed al Sulaiti as well as the ambassadors of France, Korea and Japan.

Four international construction consortia were contracted to build the three new metro lines:

- For the Red Line North the ISG joint venture (Salini Impreglio S.p.A./ SK Engineering & Constructing Co Ltd/ Galfar Al Misnad Engineering & Constructing;
- For the Red Line South the Qatari Diar Vinci Construction JV (QDVS)/ GS Engineering & Construction Corp./ Al-Darwish Enginering W.L.L
- For the Green Line Contractor Porr Bau/ Saudi Binladin Group Company Ltd/ Hamad Bin Khalid Contracting Co. W.L.L.
- For the Gold Line the joint venture Aktor / Larsen & Toubro Limited/ Yapi Merkezi Insaat VE Sanayi Anonim Sirketi/ Sezai Turkes Feyzi Akkaya Marine Construction/ Al Jaber Engineering

The project is the keystone of a wider scheme to link up Qatar. Along with other Qatar Rail projects such as the Lusail Light Rail Transit and the Long Distance Passenger and Freight Rail, its aim is to encourage the use of public transport and realise the 'Qatar National Vision 2030' masterplan.

Whatever else can be said of the project, such scale at such speed has marked Doha's place in tunnelling history

Cover
This issue's front cover shows celebrations following breakthrough on the Bangalore Metro.

Next issue
In the next issue of Tunnels and Tunnelling we have a report on the Sochi project in Russia, a site visit to the Milan-Genoa high speed rail project, a look at waterproofing concepts with BASF and Stirling Lloyd and an interview with Andy Sloan, MD of Donaldsons

This month...

30 YEARS AGO

Japan is currently examining the possibility of storing oil and liquid petroleum gases in massive underground caverns and has turned to Scandinavia for technical expertise. The Japanese are currently negotiating with the Rock Tank Group, a consortium of Swedish consultant Skandia and the contractors ABV of Sweden and Astrup Hoyer of Norway, for transfer of expertise gained during construction of many such caverns in Norway and Sweden. The Japanese are examining the development of three entirely state-run underground storage facilities with 4Mm^3 capacity.
Tunnels and Tunnelling, November 1986, p.7

40 YEARS AGO

Eight workmen were injured in an explosion which occurred early on 28 September in the second bore of the Eisenhower Memorial Tunnel in Colorado. The blast occurred 640m from the tunnel's west portal. This USD 110M project is due to be completed in Autumn 1979 and the tunnel will be 2,730m-long. The accident occurred when a miner in the middle level of a three-level drilling platform drilled a hole about 20mm away from an explosive in a hole drilled for an earlier blast that had failed to go off and had not been discovered. The drill either slid over into the old hole or the edge of the new hole cracked, detonating the explosive. The explosion did not damage the tunnel and slowed work only temporarily.
Tunnels and Tunnelling, November 1976, p.15

Breakthrough at Nordfjordur in September 2015

Downtown Edmonton Intensification

Stockholm City Line

A Vermeer D330x500 HDD rig

JAPANESE ARTICULATION FOR PHRA KHANONG PROJECT

THAILAND — The TBM set to bore the Khanong cable tunnel project in Bangkok was accepted at the Terratec factory in late September. The client, Bangkok's Metropolitan Electricity Authority (MEA) and local contractor Nawarat Patanakarn attended the event.

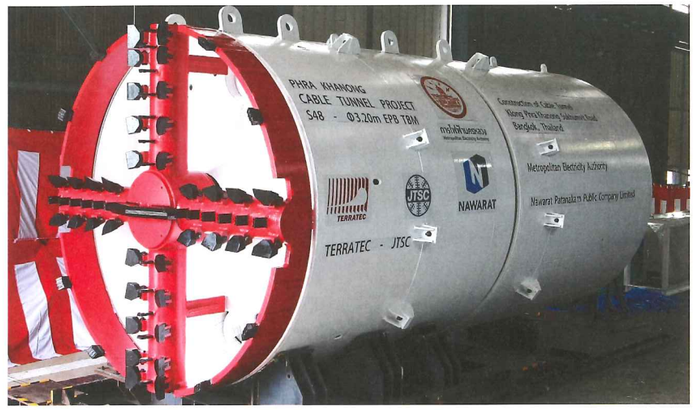
The project is one of several upcoming tunnels to accommodate new high voltage cables for the Thai capital. This drive is at an intersection in a busy area of central Bangkok and faces tough alignment constraints.

The TBM will be launched from a 7m-diameter shaft being constructed beneath a toll road ramp and then head 495m at an upwards grade of 1.2 per cent to a reception shaft. It will then be transported back to the launch shaft and launched on a second, 293m-long drive. This second drive requires the TBM to be launched into a 32m-radius curve with a 2 per cent upwards gradient to navigate through the piles of the ramp.

To achieve this, the machine was designed with an X-type articulation system that provides a maximum articulation angle of 6.6-degrees to accommodate a minimum radius curve of 30m. Although this type of extreme TBM articulation is uncommon in the global market it is popular in Japan. Terratec teamed up with Japanese manufacturer JTSC to develop the design with the aim of exporting this technology to other countries.

A spokesman for Terratec added: "Geological conditions along the alignment consist of fine sand and stiff clay, with an average overburden of 26m and a groundwater head of about 2 bars. The TBM's soft ground cutterhead features an open spoke design with the addition of knife bits to assist break-in and break-out of the steel fibre reinforced concrete shaft eyes. Traditional tapered precast concrete segments (left/right/straight) will typically be installed as the machine progresses, with shorter steel segments utilised during the course of the sharp radius curve."

The machine was due to arrive in Thailand in mid-October. Excavation is due to commence in mid-December. The tunnel is due to be commissioned at the end of 2017.



Both: JTSC assisted in development of the articulation of the machine

Sleepless locals disrupt tunnel work

INDIA— Local residents have disrupted Work on the Kuthiran Tunnel. Local media reported that the protest was against night blasting works on the new road tunnel. Work to remove the granitic spoil was allegedly also undertaken at night.

A consensus was reached that no blasting would occur between 9pm and 6am, but no decision on spoil removal was made. However, Pragati Engineering and Rail Projects Group said that night work was needed to complete the project on schedule, and threatened to withdraw from the work.

Company representatives told Indian newspaper 'The Hindu' that the nearest house was nearly 4km away and that closer inhabitants were resettled elsewhere prior to work.

Locals have threatened a dharna (a non-violent sit in protest) at the portal if night work continues.

Alaskan Way passes halfway point

USA— The TBM mining the Alaskan Way Viaduct Replacement Tunnel passed beyond the halfway mark of a 9,270ft (2,825.5m) tunnel on September 30, the Washington State Department of Transportation announced on 3 October. Seattle Tunnel Partners has now excavated more than 4,635ft (1,412.8m) of the SR 99 tunnel, with much of that progress occurred during the past five months. STP tunnelled more than 3,000ft (914m) since leaving a planned maintenance stop on April 29 to begin the push beneath the viaduct.

The TBM is now about 190ft below the surface and will undergo a brief planned maintenance stop. WSDOT said the 90ft- (27.4m-) deep receiving pit at the north end of downtown Seattle is largely complete, along with many other aspects of the portals.

Louisville scraps sewer basins

USA— The board members of Louisville, Kentucky's Metropolitan Sewer District (MSD) unanimously agreed to move forward with a plan to replace three proposed sewer basins with a tunnel.

Initially plans called for half a mile of tunnel, which will now expand to a full 2.5 miles. The sewer basins are part of efforts to mitigate stormwater overflows.

Skanska wins major Norwegian hydropower job

NORWAY — Swedish contractor Skanska has won a NOK 657M (USD 80.8M) contract from Eidsiva Vannkraft to construct Nedre Otta hydropower plant.

The project, to be located in the municipalities of Sel and Vågå, will include the construction of the power station and transformer hall. It will also involve nearly 12km of tunnel work.

Bodies recovered from MWSS tunnel project

PHILIPPINES — Last month rescuers recovered the bodies of six workers killed on the Sumag River Diversion project. All six worked for contractor Cav Deal.

The project is a 600m-long PHP 717M diversion of the Sumag River being carried out for client Metropolitan Waterworks and Sewerage System (MWSS).

Large scale investment in Scottish sewerage

GREAT BRITAIN — Investment is to be directed at the sewer network of Paisley in Scotland. Client Scottish Water is about to spend GBP 17M on a 1.6km sewer tunnel as well as combined sewer overflows (CSOs) in the town centre. The work will reduce the frequency of spills into local waterways during storms.

The investment is the biggest of its kind made by Scottish Water in Renfrewshire and is part of the company's GBP 250M, five-year programme to improve river quality, the natural environment and to tackle flooding in the Greater Glasgow area. This is the same investment packet that funds the Shieldhall Tunnel in southwest Glasgow, the biggest investment in the area's wastewater infrastructure for a century.

The project in Paisley was due to start on 10 October and is expected to take two years to complete. The contractor is Amey.

The new stretch of sewer will have a diameter of up to 1.5 metres and will be installed at depths of between 4m and 20m. A total of 15 shafts will be installed along the sewer route, with the MTBM tunnelling between them.

Amey will also be installing a launch chamber and diverting two water mains before the main work starts.

Joanna Peebles, Scottish Water's regional communities team manager, said: "This important project will significantly improve the environment on the White Cart and the Espedair Burn and, in turn, the River Clyde. "Scottish Water has liaised with all relevant organisations and stakeholders, including Renfrewshire Council.

"We can assure local residents, businesses and road users that we will do everything possible to minimise any disruption and would stress that any inconvenience will be far out-weighed by the long-term benefits to the local environment that this investment will deliver."

The Greater Glasgow area investment follows years of collaboration and studies by the Metropolitan Glasgow Strategic Drainage Partnership (MGSDP), whose partners include Scottish Water, the Scottish Environment Protection Agency (SEPA), Glasgow City Council, Renfrewshire Council and Scottish Canals.

LETTER: DUST MONITORING

I welcome the introduction by Trolex of a real-time respirable dust monitoring instrument (Dust Buster, T&TI September 2016). The tunnelling industry is very used to continuous atmospheric monitoring for gaseous contaminants having progressed from hand held instruments in the 1980s and 1990s to sophisticated fixed systems on most large tunnelling sites today but till now continuous electronic monitoring of dust levels has not been possible.

Dust has always been an occupational health problem in conventional tunnelling particularly in rock however for a long time now most UK tunnelling has been with TBMs in soft ground and we have largely forgotten about the problem of dust. It is only with Crossrail and the extensive use of SCL that dust has again become recognised as a major hazard in UK tunnelling.

Dust exposure is normally measured as an 8-hour average exposure. This technique may be satisfactory for factory processes in which reasonably constant levels of dust are generated. However, in SCL tunnelling, dust levels vary widely during the work cycle and the technique of 8-hour averaging may not give a true assessment of exposure risk. HSE prescribes the method for sampling dusts in publication MDHS 14/4 and suggests a minimum sampling period of 2 but preferably 4 hours. Air is drawn over a filter positioned close to a person's breathing zone and the mass of dust collected along with the volume of air sampled combine to give an average exposure.

Hopefully instruments will shortly become available which will give real time instantaneous or short term (15 minute) inhalable and respirable dust exposure levels. This will allow a much more accurate assessment of dust levels over an area of the tunnel where dust is being generated. The selection of respiratory protection based on control of peak exposure rather than long term average exposure could then be undertaken leading to better worker protection.

The tunnelling industry should embrace electronic dust monitoring as enthusiastically as it has toxic gas monitoring and work with HSE to establish monitoring protocols based on peak and short term exposure. The BTS guidance on nitrogen monoxide exposure showed what the industry could do in partnership with HSE to address an atmospheric contaminant and similar guidance could be produced for dust exposure.

Dr Donald Lamont
Hyperbaric and Tunnel Safety

MEL ELWELL JOINS HS2 BOARD

GREAT BRITAIN — High Speed Two announced that Mel Elwell will join its board as a non-executive director. Elwell was formerly CEO of engineering and infrastructure giant Amey.

During his time at Amey the company delivered major road and rail projects, including the maintenance of the Forth Road Bridge. Prior to that he was MD at ADI group, a provider of transport services across Europe.

Commenting on his appointment, Mel Elwell said: "As well as the benefits of improved connectivity and capacity, the skills and knowledge gained through delivering HS2 will make Britain a world leader in infrastructure projects.

"HS2 is a truly exciting endeavour that has the potential transform the UK's infrastructure industry. The opportunity to play a role in creating this legacy is s too good to miss."

HS2 chairman David Higgins added: "We are looking for leaders with experience of large and complex construction challenges to advise our work, and Mel certainly fits that description.

"He transformed Amey into one of the UK's most successful engineering and infrastructure companies, and HS2 will certainly benefit from his considerable industry knowledge."

VENERABLE TBM LAUNCHES ON WHITE RIVER TUNNEL PROJECT

USA — A 6.2m-diameter Robbins TBM was launched by the Shea-Kiewit JV on the White River Tunnel project. The 8.5km drive through limestone and dolomitic rock is part of the Dig Indy wastewater tunnels complex being constructed below Indianapolis. The parent project comprises 28km of tunnelling.

The machine was previously used on the project's main tunnel, the Deep Rock Tunnel Connector (DRTC). However the DRTC was far from the TBM's first job. A Robbins spokesperson elaborated: "The machine, originally built in 1980, has been used on New York City's Second Avenue Subway, as well as projects in Massachusetts and Canada. Once the machine has completed the DigIndy network of tunnels, it will have bored more than 51km of tunnel—an achievement making it one of the hardest working Robbins TBMs ever put into service."

The TBM was launched from a 67m deep shaft following refurbishment that included new motors, gearboxes and electronics. As of the end of September, the machine had bored over 300m. About one mile into the White River Tunnel, the drive will bifurcate eastwards to bore the 2.7 km Lower Pogues Run Tunnel in front of Lucas Oil Stadium in downtown Indianapolis.

The machine will then be backed up to the bifurcation point before continuing north for completion of the White River Tunnel.

The S-K JV has until 2021 to complete the White River and Lower Pogues Run tunnels for local owner Citizens Energy Group, and until 2024 to complete all the tunnels.

The use of one TBM was seen as a positive: "The use of one machine was more efficient for our crews. The schedule allowed us to run with one TBM and we feel we can do it with one machine. It also was a less costly option than running two machines in terms of the owner funding the project," said Dan Martz, vice president for J.F. Shea. Once complete, the Environmental Protection Agency mandated deep tunnel project will reduce the amount of raw sewage overflows and also clean up tributaries along the White River.

Mucking will be carried out by continuous conveyors that will have to navigate 300m radius curves as the tunnel follows the path of the White River.

The S-K JV stands proudly in front of the 6.2m cutterhead

The TBM will have bored more than 51 km once finished with its Dig Indy tunnels

The TBM was launched from the 67m-deep White River shaft

Continuous conveyors will navigate curves as sharp as 300m along the route

NEW TO DELIVER HARDING LECTURE

Dr. Barry New

GREAT BRITAIN — Barry New is to deliver the Harding Memorial Lecture at 6pm on 19 January at the ICE in London. An associate for the Geotechnical Consulting Group, New has chosen to address tunnelling impact assessments for existing utility pipelines and tunnel assets.

"An important consideration when planning and carrying out tunnelling works is the impact that those works may have on Third Party assets, particularly in cities," said New. "Damaging ground movements and loads may be caused by the tunnelling itself and/or by associated works for shafts. The impacts of tunnelling on buildings throughout the world have been widely reported but the impacts on utility apparatus have not received such detailed and extensive attention in the literature."

The principal purpose of the lecture will be to consider strategies and methods of impact assessment for utility pipelines and tunnels. The content will be informed by numerous investigations into pipeline failures and consideration of the geo-environment of pipelines in cities, which may render conventional analyses unreliable or even intractable.

The lecture will discuss the current mainly analytical approaches to the problem and suggest other more broadly risk based methods which may be considered for future application. The emphasis will be on simplifying the assessment process to reflect the uncertain condition of the pipelines and other relevant factors but retain the asset protection essential to utility providers.

New's expertise and experience is in geotechnical engineering, tunnel and pipeline design, construction and planning with emphasis on the interaction with the urban environment. In particular New has carried out numerous forensic investigations of tunnel and pipeline failures and impact assessments for construction works involving existing tunnels, major structures and pipelines.

BTS chairman Mark Leggett will lead the evening while Professor Lord Robert Mair of Cambridge University has agreed to introduce the lecture. New worked with Mair on various projects including the centrifuge modelling research at Cambridge and the Channel Tunnel Rail Link prior to his joining the Geotechnical Consulting Group in 1995.

CAREER

Following several years at the National Physical Laboratory New joined the Tunnels Division of the Transport and Road Research Laboratory in 1974, where he was closely involved with the Department of Transport's construction research programme. It was during this period that Dr New developed the methods for the predictions of tunnelling induced ground movements and construction vibrations that have become widely adopted by the industry throughout the world.

From 1985 until March 1995 New was Head of Ground Properties and Underground Structures at the Transport Research Laboratory (TRL) and led the Department of Transports programme in that area. He also provided specialist consultancy services within the Department of Transport and to a wide variety of clients on the effects of construction works, rock excavation techniques and the interaction between pipelines, highways and heavy vehicles.

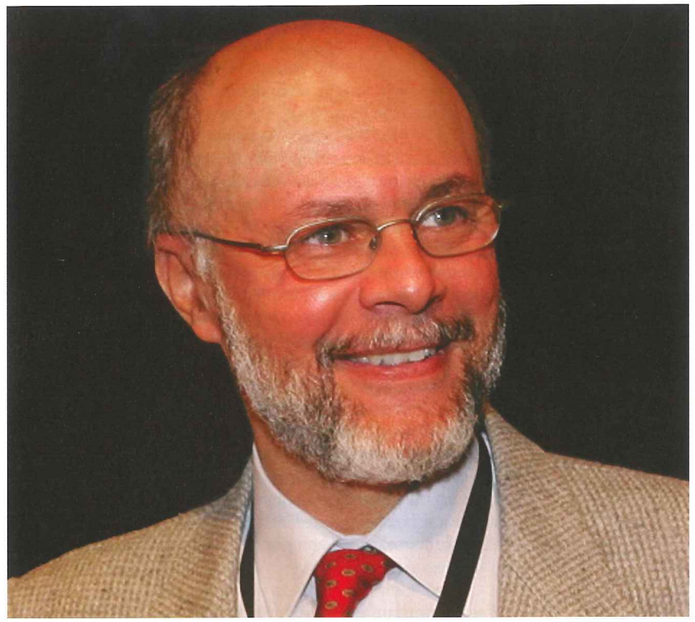
In April 1995 New joined GCG. He has been widely consulted on numerous major developments particularly beneath cities and also acts as an Expert Witness providing geotechnical/tunnelling/pipeline advice to legal and insurance groups. New has been the BTS representative to the ITA's research Working Group since 1991.

New's lecture will cover impact assessments for tunnelling on existing underground infrastructure

Left: Break through on the Copenhagen Cityringen Branch off to Nordhavn was achieved on 4 October. The TBM is captured at the moment of breakthrough on schedule into the reception shaft at Østersøgade following a drive of 1,900m from Nordhavn station. The machine contended with quarternary deposits under the railway then Copenhagen Limestone. Rambøll leads a joint venture with Arup as the client's engineer for this section

CELESTINO SETS STRATEGY

The ITA has released this Q&A with new president **Tarcisio Celestino**



Above: Tarcisio Celestino became ITA president in 2016

You were elected President of the International Tunnelling and Underground Space Association during ITA's General Assembly, last April in San Francisco. What is your own perspective of countries' demands regarding tunnels and underground space? How do you see the future of the tunnelling industry?

Tarcisio Celestino: The economic configuration is currently changing. In recent years, we have faced a long-lasting economic slowdown, during which everybody tended to curb their long-term investments. Yet, and it is good news, we are now entering a recovery phase, which implies new investments in tunnels and underground space. Until now, the sustainability factor had not been sufficiently taken into account in investment choices, which is understandable: public authorities and owners do not always have in-depth knowledge of sustainable existing solutions and environmental regulations in terms of underground construction, even though things tend to evolve in a good way. It is the role of the ITA to accompany the move of public authorities in their reflection on sustainable cities, for them to think about their underground infrastructures upstream. Indeed, if you wait for your city to face intense traffic jams before you design and develop public transports, then you will have to wait another 15 years for these problems to be fixed.

Does it mean that today is the best time for countries to think about the future of their infrastructures?

TC: Absolutely, for the world is facing a very drastic increase in urban population that will keep skyrocketing by 80 per cent in the three or four decades to come. This means more traffic, therefore more transport networks needed. With the global warming effects, cities also have to devise efficient flood regulation solutions to cope with heavy rains and the rise of water levels. Considering the existing backlogs and the fact that we have to rebuild or repair everything we have already constructed so far within the next two or three decades, the actors of the tunnelling and underground space sector have a huge market potential ahead of them. Faced with these current and future needs, our industry has to adapt and to prepare itself for growth. Regarding mechanized tunnels and tunnel monitoring, significant technological progress has been made within the last twenty years. I believe new actors will come up with disruptive innovations in the next twenty years.

A new generation of young people – engineers from various sectors notably –, studying electronics, automation, big data, or the internet of things, will create new hopes of applications in the tunnelling industry. We have to welcome these people, and inform them that the ground construction industry is a key market where they could find interesting career opportunities.

Regarding your analysis, how do you think the ITA has been coping with these opportunities and challenges?

TC: The International Tunnelling and Underground Space Association is turning 42 this year. Since its creation at the initiative of 19 nations, it has been encouraging the use of the subsurface for the benefit of public and sustainable development.

Also, it has been closely involved in the promotion of advances in the planning,

design, construction, maintenance and safety of tunnels and underground space. In addition, it has gathered relevant information, sharing the latest reflections and ideas developed on tunnels and underground space, notably through working groups and committees. Along with the increase in its members, the Association has also been working at enlarging its service offers, in order to appear as the leading reference in the sector of underground infrastructures. In 2013, the Association even set seven strategic goals to be achieved within the period 2014 to 2016. To be specific, deepening relationships with local shareholders such as Member Nation organisations was one of the main goals to reach. Indeed, the Association relies on their endorsement to undertake a project in any country.

Therefore, ITA created four boards to enhance these relationships: ITACUS dedicated to interact directly with urban and regional planners; ITACET: focusing on knowledge transfer and sharing, and finally ITATEC: aimed to create a synergistic work between industry developments, academic research and final users; ITA-COSUF: not intended to promote tunnels but to improve their operational safety and to make them more viable solutions. Significant progress has occurred since the frequent accidents in the 1990s. ITA-COSUF is partly responsible for this.

After two result reports carried out in 2015 and this year, one can note that most of them have been successfully reached. The newly elected Executive Council is currently working at a new strategic plan in order to continue along this path.

Above: ITA general assembley 2016

How does it translate into organisation and missions?

TC: Further changes had to be initiated to cope with a shifting environment, we wanted to go further in improving our organization. In 2013, the Executive Council proposed to the General Assembly and this latter decided to regularly assess the governance of the Association. The Surveillance Council was established during the General Assembly held in Geneva the same year. Dedicated to ensure that ITA's internal functioning matched a good governance, the Surveillance Council released its first report at the end of 2013 and reported to the General Assembly in 2014. The report confirmed that the ITA, recognised as an NGO, fully complies with the Code of Ethics and Conduct of Non-Governmental Organisations.

Besides, ITA built a solid communication system that has been implemented within the Association, thanks to the working groups and boards, like those mentioned previously, in order to bring the actors of the industry together and to create a genuine synergy between them. In that matter of improving processes and actions, continuous efforts are made and are still carried on.

Therefore, as of today, and thanks to the precious and regular contributions of our working groups and committees, we are on the right track. And of course, we will keep questioning and improving ourselves. But I think we have all the assets and tools to appear as a solid and credible international key speaker to the whole tunnelling community of decision-makers and public authorities.

Why is communication so important for the International Tunnelling and Underground Space Association?

TC: Communication is an indispensable condition without which the ITA cannot sustain its industry. The success of the ITA Tunnelling Awards - whose last edition attracted 110 entries -,

Below: Long Tunnels at Great Depth group meeting at WTC 2014

the success of the last World Tunnel Congress in San Francisco, attended by 2,300 people from the tunnelling industry (a record figure) and hundreds of Press articles throughout the world were perfect demonstrations of that synergy. A balance also confirmed by the strong interest displayed by the four solid candidates competing for the WTC 2019.

Eager to have tangible evidence of the satisfaction of its different members (Member Nations, Prime sponsors, affiliate members, workings groups and committees), the ITA ordered a survey in 2014, at the request of the Executive Council. It received a 'good' satisfaction rate from 70.1 per cent of the poll, which is a strong indicator of the confidence members place in it. The members' level of satisfaction is particularly high among Member Nations, concerning communication from the Executive Council, the President and the Secretariat. In the same way, during our last discussion with the ITA's Prime Sponsors in San Francisco, the latter expressed their full satisfaction regarding the Association's activities. It is very encouraging for us, for it means that our efforts to reinforce our different stakeholders' level of commitment are fruitful. It is the only way we can make the tunnelling and underground space industry vivid and visible to the world.

The world will keep evolving at a fast pace, either demographically or technologically speaking. Hopefully, new Member Nations will join us, new strategic needs will emerge. The new Executive Council is fully aware that these external factors require us to pursue our desired improvements on the ITA's management and external actions. New ideas and proposed actions are currently being discussed, for an early operationalisation.

Above: Life Cycle Asset Management meeting at WTC 2014

As the new President of the ITA, what will your road map and priorities be for the next three years? What could the ITA's new perspective be for the upcoming decade?

TC: My first goal is to undertake concrete actions to influence government decision makers to significantly increase the use of underground space around the globe. In that matter, as I said before, we have strong opportunities, such as urban development, growing needs for energy and water supply and storage, and hopes for underground developments in the mining sector. To make it work, we need to keep addressing strong messages to the general public, by bringing people strong and regular evidence of the benefits of using underground infrastructures (in terms of security and resilience, in particular).

This will necessarily involve regularly putting the costs of infrastructures into perspective, bearing in mind that the costs of underground works are not as high as they are said to be with respect to the benefits and the returns on investment generated for populations.

Yet, it is clear that rising awareness among international decision-makers cannot be achieved without the support and involvement of the Member Nations, together with the whole industry. This must rest upon state-of-the art research and regular assessments of our activities, for completed tunnels and underground spaces around the world are our most valuable assets.

For this reason, in accordance with its strategic goals approved by the General Assembly in May 2014, the ITA has been striving for more regular and substantiated feedback from its different Working Groups ever since. There have been regular meetings of the Executive Council with Working Group Leaders and Committee Chairs. These discussions have resulted in the launch of a new Peer Reviewing Process, in order to assess the solidity and technical soundness of the works. This way, the ITA betters its odds to strengthen its influence on the academic and political field, while enlarging practical application possibilities through its research work. More generally speaking, and while some countries remain in their early phase in terms of use of underground infrastructures, the ITA will pay particular attention to knowledge sharing, thanks to its working groups and through the organization of training sessions and symposia. If we succeed in convincing decision makers to adopt underground solutions, therefore having more resilient cities, we will create a boom in our underground construction industry. That is exactly what we are planning to do

UNDER CUT

In February 2016 construction company Bessac completed work on a protection tunnel in extremely difficult geology in South Florida. In just ten months and using a customized machine designed especially for the mission, a 3.13m Herrenknecht Combined Shield, 1,613m were tunnelled adhering to the highest safety standards. A new sewer line was installed in the finished tunnel – after half a century in use the old pipe was simply worn out. This report from the TBM manufacturer describes some of the challenges

THE GROUND CONDITIONS and project circumstances of the mission at Norris Cut were anything but standard. Not only did the karstified, permeable geology pose the risk of flooding the machine. The complex Fort Thompson Formation to be tunnelled through was also full of sand-filled cavities. The tunnel face was therefore prone to instability.

For this reason the construction of the protection tunnel for a new sewer line between Virginia Key and Fisher Island required a special and highly flexible machine with exceptional safety features. A Herrenknecht Combined Shield was chosen for the bore: available in slurry mode as well as in EPB mode depending on the requirements, the HCS machine is optimally prepared for changeable ground conditions.

Additionally, the front area of the machine had to be accessible at all times to allow for tool changes. For maximum safety a bulkhead with a dive pit was developed especially for the project. Because of the bulkhead between the front two machine parts, and the overpressure thus enabled, muck and water could not penetrate into the machine at the tunnel face. Should high water pressures lead to flooding regardless, the dive pit allows safe locking into the flooded area.

Below: The 3.13m machine showing project stakeholders

In the end however these safeguards were not needed. Neither the lock system nor the EPB mode of the HCS machine were used. The ground was highly permeable as expected, however the contractor was only required to perform one maintenance stop, which was carried out under compressed air after ground treatment from the TBM.

The machine began the drive near the treatment plant on Virginia Key in April 2015. Right from the very first, the project was characterised by the requirement to save space. With a diameter of twelve metres, the launch shaft was rather small. At the beginning there was no room for the HCS machine's back-ups and they were only able to be used one by one after 70m of tunnelling.

Left: In February 2016 "Dorsey" reached the target shaft on Fisher Island

Above: Aerial view of the worksite

For the first section the TBM needed to be pushed forward in pipe jacking mode using a jacking frame adapter developed by the contractor, the rest of the tunnel was then lined with concrete segments.

In the months that followed the 3.13m diameter machine, nicknamed Dosey, dug its way forwards at a depth that reached 21m below sea level.

After 227 working days, on 16 February, the machine broke through on Fisher Island. Top advance rates of up to 24m per day were achieved with about 300m per month.

By the end of the year the new 60" (1.5m) discharge pipeline is due to be installed in the finished protection tunnel and put into operation.

The successful drive on the Norris Cut project has pushed the boundaries of what is possible in Florida's tunnelling industry and contributed to its further development: "The project has set standards for work in Florida's underground and showed solutions for deep sewer lines in the porous Fort Thompson Formation," confirms Bernard Theron, president of Bessac.

A Herrenknecht spokesman added: "With the construction of the Port of Miami Tunnel already, machine technology from Herrenknecht had demonstrated that even the most complex ground conditions such as the Fort Thompson Formation can be safely mastered with optimally adapted technology.

"Despite its huge diameter of nearly 13m, in 2013 the EPB Shield S-600 reached its target reliably thanks to an additionally installed slurry circuit. According to accounting and consulting firm KPMG, in 2012 the Miami Port Tunnel was one of the ten most innovative projects in the world"

NORTHERN CHALLENGES

Road tunnel excavations in Iceland are a tough test of endurance in complex geology, such as at the Vadlaheidi project. Report by **Patrick Reynolds**

ICELAND HAS AN APPROACH to tunnelling that seeks the rock to play the prime role in road tunnel performance without, as often elsewhere, significant and heavy use of permanent concrete linings, where possible. The approach builds on the drill and blast excavation heritage of the Norwegian tunnelling sector.

However, as a large island nation in the north Atlantic, sat square upon a spreading ridge of parting tectonic plates, the geology of Iceland continually presents complex and varying combinations of rock and groundwater conditions to fascinate, frustrate and typically surprise, despite best efforts. The geological challenges that arise on road tunnel projects are complex and, for tunnellers, do crop up as different challenges with some frequency. Most commonly, the tunnelling challenges feature two excavation problems: faults zones of varying size; and, lots and lots of water – usually cold, but not always.

Below: Heavy support needed to advance through east side weak zone at Vadlaheidi
PHOTO: ICELANDIC TUNNELLING SOCIETY, UNLESS NOTED

Most recently, the geological challenges have shown particular extremes on the Vadlaheidi toll road tunnel project, located in the mid-north of the country, closest to the Arctic Circle. The progress of excavations at Vadlaheidi have been drastically slowed, with both drives from the portals hindered by different problems.

On the east side, tunnelling was brought to a halt in early 2015 by a forceful combination of the two core problems – weak shear zones and massive inflows, respectively. After some months, and following a massive pumping effort, work is ongoing to

Above left: ***Project locations within Iceland***

Above right: ***Lengths of tunnel projects in the country***

stabilise and recover the tunnel.

On the west side the problem is water again, but of a different character. The challenge is twofold: large inflow rates, and the groundwater has been extremely hot, temperatures lessening only of late. A massive grouting regime is in place, merely to obtain the chance to edge the face onward.

Tunnelling on the project has been very challenging, remarks Bjorn A. Hardarson of consultant Geotek, which is providing site supervision services to Vadlaheidi project.

Being Iceland, the geological challenges at Vadlaheidi are not the first time significant excavation challenges have been experienced in road tunnel construction, merely the latest and affording fresh opportunities for tunnellers to face and solve seemingly continuous problems, and struggle on.

The roster of road tunnels is being added to despite the technical challenges; success comes eventually, and is needed. The benefit to be won is having all-weather subterranean routes, liberating more of the remote, scattered, towns and communities along the freezing fjordic coastlines, and those tucked in snow-filled valleys, over long dark winter months.

Among road tunnel projects built in recent years are the Hedinsfjord, Almannaskard, Faskrudsfjord and Oshlid schemes. Under construction are two key public road projects – Vadlaheidi and Nordfjordur, which are the country's longest two road tunnels; and, at Husavik – an industrial haulage tunnel route only, on which tunnelling was nearing completion as *Tunnels & Tunnelling* went to press. Projects to come in the near term include Arnarfjordur-Dyrafjordur for which prequalification is underway, says Gisli Eiriksson, director with Vegagerdin (Icelandic Roads and Coastal Administration).

As plans are etched and firmed in the far north, potential projects for the future could include road tunnels at Sundabraut in Reykjavik, Mid-Austurland, a further subsea tunnel below Hvalfjordur, and schemes potentially also at Lonsheidi and Vopnafjordur-Herad.

VADLAHEIDI

Vadlaheidi is Iceland's second longest road tunnel, though it has the largest cross-section profile of a tunnel open to public traffic. It is a single tube being built to run east-to-west from Fnjoskadalur, an inland valley, to Eyjafjordur, the long fjord opening to the north while back south, at the head of which, is the region's principal city, Akureyri.

The tunnel is approximately 7.5km long, including 320m of concrete portals, which keep access clear of the deep and widespread snow each long near-Arctic winter. Within the mountain, geology is basalt with interbedded sedimentary layers. Excavation had anticipated mixed face conditions.

The excavation challenges have proved more extreme, the project has been delayed and construction is still underway. Vadlaheidi has had possibly the most challenging tunnelling experience of road tunnels in Iceland so far. Once completed, though, Vadlaheidi will provide an all-weather route to open up communications and economic opportunity year-round, expanding the regional network of such roads around Akureyri.

The strategic effort to improve all-weather transport in the region had its most recent major investment at the Hedinsfjord scheme, opened in 2010. It is located north of Akureyri, and is farther from the town than Vadlaheidi. Until Vadlaheidi is finished, Hedinsfjord can boast having the longest road tunnel

Below: ***Progressive collapse at the Vadlaheidi tunnel***

(Olafsfjordur – 6.93km, plus portals) in the mid-north of the country.

The Hedinsfjord project was developed by the roads authority, Vegagerdin. During construction, Hedinsfjord had its own significant geological challenges in tunnelling due to groundwater, though not as much as Vadlaheidi has been experiencing.

Project developer for the Vadlaheidi road tunnel is Vadlaheidargong Ltd, which took on project development from the road authority, still acting in a design role on the project. The project works are funded by a state loan, to be repaid through toll revenues. The toll road tunnel was planned to be in service by late 2016. In the project procurement stage, bids came in too high or so close to the available budget that the Ministry of Finance was called upon to re-assess the cost-benefit of the project.

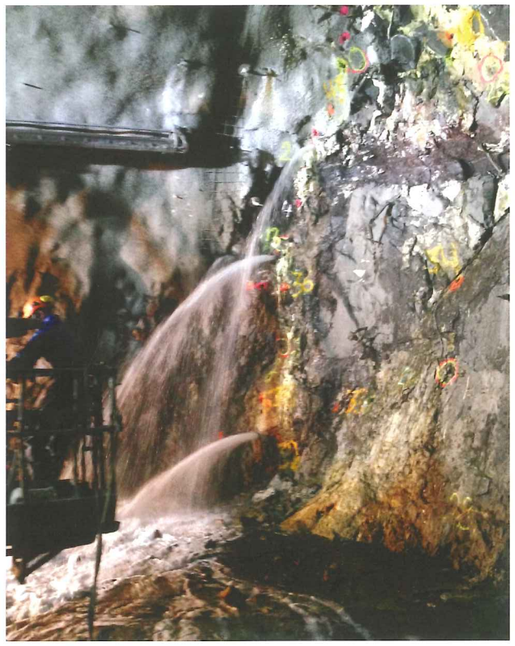
Following the review, the main characteristics of the project design were re-affirmed: a single tube tunnel with a finished width of 9.5m at carriageway level and clearance height of 4.6m above the surface. Running through a mountain range that edges a fjord, Vadlaheidi's is not only to be Iceland's second longest road tunnel in the near-term it also has the largest profile (T9.5, 66m²). The cross-section is enlarged at regular intervals to provide turning bays and service recesses.

The unit price construction contract was awarded to Osafl, a joint venture of Swiss firm Marti and Icelandic company IAV. The JV submitted the lowest of the four bids and was the only tenderer to come in below the project budget, albeit tight to the limit. Site supervision services are provided by Geotek and Efla.

Tunnelling work involves a total of 7.2km of drill and blast. Excavation started in Q3-2013 at the west side of the project, a little way from Akureyri and easily accessed. It wasn't long before the initial complexion of excavation problems were met, however, and they only kept building.

A year into the tunnelling, by late 2014 the face had advanced only slightly more than 3.2km. The original construction schedule anticipated tunnelling to be completed by late 2015, but the scale of the geological challenges thwarted that goal, and tunnelling still continues on the project. Most recent data, from the end of August, show the excavation has advanced a total of almost 5.9km – or slightly more than 81 per cent – of the length of the single tube to be blasted through the rock. But, as Geotek's Hardarson notes, there remains only 1.35km of excavation to be completed.

The distance advanced may have been only slowly added to but the achievement in the circumstances have been gargantuan, especially given the radically different, and extreme, geological conditions the tunnellers have encountered: hot on one side and cold on the other. Both wet. The different challenges have been constant for the tunnellers to contend with patiently as the west and east faces slowly close upon each other, now barely a few kilometres apart through the rock.



Above: ***Hot inflows at the west side of Vadlaheidi***

VADLAHEIDI: WEST SIDE STORY

Tunnelling on the Vadlaheidi project started on the west side but after advancing 1.9km the progress rate dropped on meeting sustained geothermal inflows. Extensive grouting was tried with limited success.

With the temperatures of the rock up to 60°C, the geothermal inflows got up to about 46°C. Steam formed near the face, and much of the tunnel approach had reduced visibility, affecting working hours as well as sequences of activities such as mucking out.

The hot water and humid conditions became so difficult that work was stopped, temporarily, in August 2014. From coming into contact with the geothermal zone, the face had only slowly advanced another 825m in the worsening conditions.

The aim on the project, then, was to switch effort to the other side of the tunnel – on the opposite side of the

Icelandic geology

The geological age of rocks in Iceland is widely spread, and gets progressively older the farther from the tectonic rift that runs diagonally from the southwest to the northeast, through the heart of the north Atlantic island, born of millennia of volcanism.

The tectonic plates are drifting apart at about 2cm/year, leaving the gap to be filled with either extrusive or intrusive igneous rock along the active diagonal zone.

Most of the road tunnels that have been built or are planned in the country are around the rugged fjord coastline, typically in the oldest of the bedrock formations, which can be up to 16M years old. Hydro development is typically inland.

Bedrock in the island is dominated by subaerial basalts, ranging in strength up to 300MPa. The basalt layers are generally no more than 10m thick.

The basalts typically are weakened by fault zones, which are mostly sub-vertical and contain breccia that is often well-cemented to the bedrock. Geological features also include dykes. The faults and dykes are the key channels for groundwater, but the water is also in rock weak zones such as contact zones of successive lava layers and cooling joints, respectively.

*Above: **Flooding at Vadlaheidi***

mountain range. However, just over half a year into those works, the east side ran into its own problems in early 2015. So severe were the problems that the focus of construction activity had to switch back to the mothballed west side.

After an interval of about nine months, therefore, tunnelling resumed on the west side, in May 2015. Having had time to prepare, though, the works on the west side were able to resume supported by extra ventilation equipment to handle the hot and humid conditions, and introduction of an even larger-scale regime of grouting, with a two-part mixture.

But as the excavation slowly advanced uphill (at 1.5 per cent grade), the temperature of the hot inflows continued to increase, eventually peaking at 65ºC. Probing is being done 30m-40m ahead of the face. Large volumes of grout were injected into the rock mass ahead of the face to stem the scalding flows, reducing the inflows sufficiently for each blast round to advance the face.

It was not clear if it would continue higher still, nor where and how the geology would eventually change, in the rock ahead, into the cold water zone experienced by the flooded, static tunnel on the east side.

By the end of 2015 the contractor had completed approximately 3,135m of excavation on the west side, or approaching two-thirds of the planned drive for that section. Temperatures, however, were beginning to pull back, slowly.

So far this year, tunnelling on the west side had advanced approximately a further 1,250m as *Tunnels & Tunnelling* went to press. Inflow temperatures are down to half their peak level.

Progress has been around 20m-40m per week, typically, adds Hardarson. Occasionally though there is a surge, like more than 60m achieved in a week in late August.

In total, by late August, the west side has advanced more than 4,380m – almost 88 per cent of what has been planned for the section. Excavation on the other face, though, has yet to properly resume following the extensive recovery works.

VADLAHEIDI: EAST SIDE STORY

Tunnelling on the east side of the project started earlier than planned due to the slow progress caused by geothermal inflows on the west side. Excavation got underway in September 2014 and quick progress was achieved – in under two months the face had advanced about 380m.

Excavation pushed on, advancing downhill, until early 2015 when a sub-vertical fault zone that had been passed without problem then gave way without warning in a progressive collapse. No one was injured.

The face had already moved beyond the fault into reasonably okay basalt and was set to advance farther when the roof began to collapse some metres back. Cold water inflow began and continued, steadily, and deepening to eventually flooding most of the length of the tunnel. From the face, the tunnel was fully submerged for about 600m back uphill, then partly flooded up towards, but short of, the portal area.

The works on the east side have been focused on recovery of the tunnel. As such, given the extensive pumping and then continued dewatering required, and stabilising the tunnel in the weak zone, the east side has made little progress for almost one and a half years.

The tunnelling work involves extensive consolidation grouting for stabilisation, and the grouting above the tunnel started in February of this year. To slowly open up the fault zone, heavy excavation support comprising pipe umbrella, steel beams, lattice girders, wire mesh and more than plenty of shotcrete.

By the end of August, the east side was still using the grout and stabilisation system to work through the weak zone, to at least recapture the previously held advance of 1,475m before the collapse and flood. The zone is about 15m thick, and water still emerges from the tunnel face, remarks Hardarson.

NORDFJORDUR PROJECT

The Nordfjordur project is located on the east coast of Iceland, near the town of Eskifjordur, and key infrastructure is a 7.9km-long single tube (including about 370m of concrete portal structures). The total length of the project ranks

*Below: **Fnjosk consolidation grouting***

Nordfjordur as the longest road tunnel under construction, and will be the longest in service when opened, expected in late 2017. It also includes approximately 7km of access roads.

Vegagerdin is developing the road tunnel. The scheme was approved by the Government in early 2012, saw construction start in late 2013 and achieved completion of the excavation phase two years later, in late 2015. Contractor on the project is a JV of Metrostav (completing its second road tunnel in Iceland – the first was leading the JV that built Hedinsfjord) and local firm Sudurverk.

With completion and fit-out works well underway, Eiriksson says the road tunnel is to be officially opened to traffic in September 2017. Plans and designs for the project were developed by local consultants including Mannvit, Verkis and Efla.

*Above: **Breakthrough celebration at Nordfjordur tunnel in September 2015***

TUFF CHALLENGE

Geology along the tunnel alignment is mostly layers of basalt with variable scoria near the boundaries. There are also sedimentary layers, notably orange-red tuffs, presenting layers of variable thickness. Unusual for an Icelandic road tunnel, little groundwater was expected – and there was relatively little experienced.

The tunnelling challenge was in the weak tuffs, primarily at the south side of the tunnel, near Eskifjordur. Excavation rates would often drop by three-quarters when the face would advance from drill and blast method in basalt rock and approach the dry sedimentary layers. Extensive support was required to carefully advance through the tuff layers. The steps included pre-dig installation of a canopy of poles, and then installation lattice girders and shotcrete at each 2m, short-step, advance of the face on those stretches.

The halfway mark in excavation of the T8 profile tunnel (8m wide at the base) was reached in during 2014. With progress having continued as anticipated, tunnel breakthrough on the project occurred just over a year ago, in September 2015.

The contractor is now half-way through two further years of construction activities to complete and open the road tunnel to traffic, in 2017 – an opening schedule that has remained steadily on course. Current work includes installation of the waterproof lining and technical stations within the tunnel, and also on construction of a total of 366m of concrete portal structures.

HUSAVIK, FUTURE PROJECTS

The Husavik tunnel project is located in the mid-north of Iceland, farther northeast than Vadlaheidi from the regional main city, Akureyri. Husavik is one of the shortest road tunnels built in recent years, at slightly more than 1km long, including the relatively short portal structures. Its excavated width and maximum height are 11.3m and 7.6m, respectively – making it the largest cross section of any road tunnel in Iceland. However, the tunnel is only for use by industrial trucks to reach Husavik harbour, and is not for open public traffic use.

As *Tunnels & Tunnelling* went to press, breakthrough at the tunnel was expected around September, says Eiriksson. On the project, Geotek has been providing site investigation services.

Eiriksson adds that the Husavik project is expected to be fully completed and officially opened to traffic in approximately a year – about September 2017. The timing of the opening almost coincides with the scheduled opening of the country's longest road tunnel, Nordfjordur.

The Arnarfjordur-Dyrafjordur project is located in northwest Iceland, cutting through the mountain chain separating the fjords of Arnarfjordur and Dyrafjordur. Geology in the area is again basalt with interbedded sedimentary layers.

The total length of the road is approximately 5.6km, including concrete portals. Prequalification for the construction work on Arnarfjordur-Dyrafjordur is underway, and excavation is expected to start by mid-2017, says Eiriksson. The scheduled opening of the tunnel is Q3-2020.

The second subsea tunnel below Hvalfjordur, near Reykjavik, has been looked at as a toll crossing. In the same area of the country, the Sundabraut scheme has been examined as a double tube tunnel.

Should it be built, it is the Mid-Austurland scheme that could grab the record for length in future, and by a long margin. Nearby, to the north and south, respectively, could also be the Vopnafjordur-Herad and Lonsheidi projects.

Steadily, and despite what its never-dull geology throws up, Iceland is adding to the number of road tunnels being built around the coastline to provide better access and all-weather links to its scattered communities

NAMMA METRO

Bangalore's metro construction was never supposed to be so complex, but after years of difficult tunnelling and unexpectedly harsh ground conditions, it had proven itself otherwise. With multiple TBMs boring in the north-south and east-west directions, the critical path lay through Majestic Station, a crossroads for both lines. Robbins field service were called to the job, Robbins technical writer Desiree Willis reports

Namma Metro, meaning "Our Metro", has been highly anticipated by the city of Bangalore's 8.5 million residents since it was first approved in 2010. In phase one, owner Bangalore Metro Rail Corporation (BMRCL) – a joint venture of the Indian Government and the Government of Karnataka – slated 42.3km of rail in two lines. Of that, 8.8km is underground with the remainder elevated or at grade.

Two slurry TBMs were procured for the east-west line work, while three EPBMs were procured for the critical north-south line, a full 24.2km route through the heart of the city with a total of 24 stations.

Above: Success on the Namma Metro in Bangalore

The two EPBMs "Krishna" and "Kaveri", originally manufactured by Herrenknecht, were launched from the south ramp in October and November of 2012, and were slated to bore three sections of tunnel each, totaling 1,550m. While the first 400m-long drive from South Ramp to City Market station went well, the TBMs encountered severe ground conditions on the second, 432m-long drive from City Market to Chickpet Station.

The drives took 12 and 22 months, respectively, and were hampered by a mixed face comprising hard granite and soil, high groundwater levels, and tunnelling near fragile, historic building foundations in some cases hundreds of years old.

Contractor Coastal Projects (CPL) has also said that the TBMs in this section encountered large boulders as well as reinforced blocks of concrete that damaged the TBM cutterheads. This, combined with regular cutterhead interventions and an inability to grout unstable areas from the

surface due to congested residential areas, resulted in reduced advance rates.

It was at this point that contractor CPL and owner BMRCL approached Robbins and asked it to take over the operations of the TBMs as the critical path tunnels needed to be brought back up to speed. The last 750m drive between Chickpet and Majestic stations was all that stood in the way of opening a substantial section of Namma Metro's Phase One.

After obtaining agreement from the project owner and the contractor, Robbins took over the responsibility for all aspects of the underground operations.

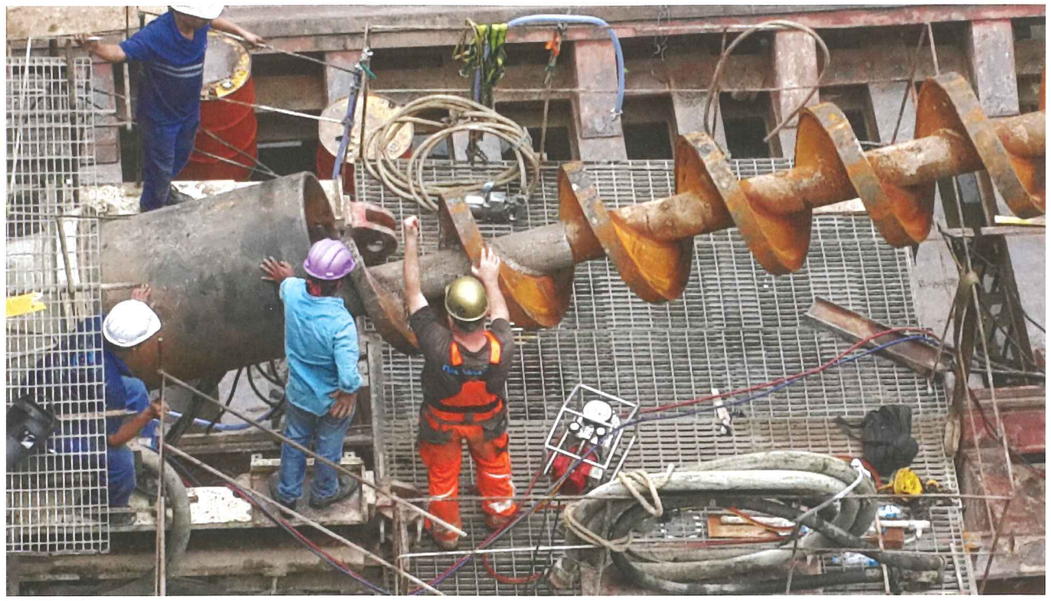
"We provided a team of over 60 staff including TBM operators, TBM technicians, ring builders, a grouting team, and more. We were also responsible for running surface installations and equipment such as the grout batching plant, gantry cranes and power supply. Contractor CPL provided a team of people including surveyors, QC engineers, and loco operators who reported directly to our site management team," explains Jim Clark, projects manager for Robbins India.

The Robbins crew carried out refurbishment of the two TBMs. In particular TBM "Krishna" underwent 112 days of repairs and testing. The refurbishment, and subsequent assembly and launch of the two machines, was carried out even as the Chickpet station was being constructed in order to mitigate any further delays. "Apart from the tunnelling operations we had to operate out of a station box where many civil engineering activities were taking place at the same time.

Both: The success of the two EPBs is all the sweeter given the challenges, including unconsolidated ground, low cover, and uncharted structures

"Great care had to be exercised in coordinating train movements bringing spoil from the TBM and lifting spoils to the surface, and also the lowering down of supplies (i.e., segments, pipes, rails, etc.)," says John Simm, Robbins field service site manager.

The two TBMs were re-launched in 2015 on their last drive—in March for TBM "Kaveri" and in December for TBM "Krishna."



Top, both pages: Refurbishment and assembly of the two EPBs

Above: Break through of TBM "Kaveri" on June 8, 2016 at Majestic station after a 750m drive

Left: Despite the challenges, the TBMs were able to excavate at rates of up to 50mm per minute in highly weathered rock

A GAUNTLET OF CHALLENGES

While TBM "Kaveri" launched first, it wasn't immune to challenging conditions. "Robbins had a geologist onsite, conducting face mapping for the duration of the project," explains Clark. The initial 160m of the drive was found to consist of residual soil, gradually transitioning into a mixed face of soil and highly weathered granite over the following 100m before finally becoming a full face of fresh granite in the last 50m. The zone of transition was particularly difficult.

"During the first drive, we had difficult geology in the face for large parts of the tunnel. We had competent rock in the face but just above the cutterhead was residual soil--this soil would occasionally fall due to the vibrations when boring the stronger rock in the majority of the face, and as a result of these conditions, it was not possible to maintain hyperbaric air pressure during cutterhead interventions," says Simm.

The problem was compounded by the presence of sensitive building foundations overhead that required minimal settlement. This problem was overcome by pumping a weak-mix grout solution into the ground surrounding the TBM. The solution permeated into existing voids and effectively prevented air from percolating through to the surface. A period of approximately 36 hours was initially required for curing of the grout solution but on-site trials with various additives enabled the standing time to be reduced to 12 hours.

"We inherited a process from the contractor that involved pumping a very weak mix grout into the cutterhead chamber, which involved a 32-hour curing period. Because of its fluidity this didn't always work and the process had to be repeated if air losses continued. As this was counterproductive to the project timelines, Robbins carried out trials using sodium silicate and other additives. However, there were concerns about trapping the shields during longer cutterhead interventions, and eventually we found a grout/bentonite mix that resulted in a 12-hour curing time and was successful in every intervention," says PN Madhan, engineering geologist for Robbins India.

Difficult ground was not the only obstacle, however. "One of the biggest challenges faced on the project was the existence of several uncharted wells along the alignment of the tunnels," says Clark.

In cases where well locations were known, the wells were back-filled with lean-mix concrete. This proved to be successful in most cases; however, some leakages of ground conditioning foam and air pressure were recorded in the vicinity of some of the back-filled wells. For known well locations interventions were carried out and all worn cutter tools replaced in advance of reaching the locations. The same procedure could not be done for the uncharted wells though.

"Several of the uncharted wells were directly along the tunnel alignment and the first sign of their existence was the presence of old pottery and bottles appearing through the screw conveyor discharge," says Clark. "It wasn't possible to implement mitigation measures for boring through the uncharted wells as we encountered them unexpectedly. By the time the excavated material had become a component of the muck in the mixing chamber and eventually came through the screw, we had bored through the well.

"It was decided that the best course of action was to continue boring and maintain face pressure." Clark also notes that the voids that made hyperbaric changes more difficult seemed to occur around the wells, whether charted or uncharted. "We concluded that, over decades, water flowing into the wells from the surrounding geology has carried fines into the wells, resulting in voids."

Excavation under sensitive building foundations presented a further obstacle. "One issue that was encountered was surface vibration while boring through rock stretches beneath residential buildings. Although peak particle velocity (PPV) values were only around 1.5mm per minute there were the usual issues regarding human response to tunnelling-induced vibrations. It was decided that the maximum cutterhead speed during the day shift would be limited to 1.8 RPM and this was reduced on the night to 1.2 RPM," says Clark.

TWIN SUCCESSES

Despite the challenges, the TBMs were able to achieve advance rates of 50mm per minute in highly weathered rock and 22mm per minute in sections of competent hard rock. TBM "Kaveri" completed its final breakthrough in June. The second TBM "Krishna" had the advantage of known geology and charted wells, and completed its excavation in about nine months on 23 September. "Logistically our environment was changing on a daily basis, so to keep up good levels of TBM production was a testament to our team in overcoming the daily challenges," says Simm. The success of the TBMs was dependent on good cooperation from all those involved. For Clark, involvement in all components of the underground construction was a point of pride.

Cleanup and final commissioning of the tunnel will be completed in 2017, and is the last obstacle before BMRCL can open the Malleswaram-Majestic link. Now that tunnelling is complete through the Majestic Station, the North and South runs of the Namma Metro will be connected--a line that, once in service, will carry an estimated 40,000 passengers daily. It is anticipated that Phase One of the metro will be opened in its entirety in 2017

WATERFRONT WORK

With a focus on improving the water quality and reducing combined sewer overflows, Toronto Water is undertaking its largest tunnelling programme to date. **Nicole Robinson** reports on the design of the Don River and Central Waterfront Project

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IN 1987 TORONTO'S WATERFRONT was cited as one of 43 polluted areas of concern in the Great Lakes Basin, largely due to poor water quality conditions in the Don River and the Inner Harbour.

An environmental assessment found that a main source of water pollution is stormwater runoff and combined sewer overflows released from outfalls into the waterways after heavy rains or snowmelts.

The solution is the City of Toronto's biggest tunnelling programme—the Don River and Central Waterfront (DRCW) project, which will reduce wet weather flow overflows into the Inner Harbour of Lake Ontario, the Lower Don River and Taylor-Massey Creek.

Two of the tunnels proposed for the 22km-long system cross buried bedrock valleys with reduced rock cover in several locations.

"The risk of encountering weathered bedrock, significant groundwater inflows or surficial soil deposits through these buried valleys was thought to be significant," says Daniel Cressman, Toronto area tunnel lead for Black & Veatch's Water Division, which, in association with R.V. Anderson Associates Limited, is undertaking detailed design and contract administration for the tunnel project.

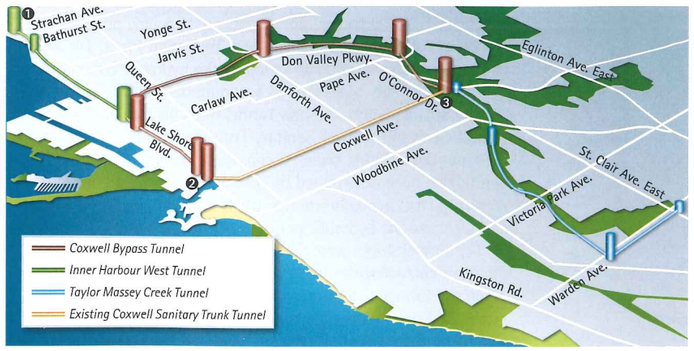
He explains, "the typical approach in the Greater Toronto Area has been to excavate the Georgian Bay shale with an open faced main beam type rock TBM and install temporary support directly behind the main shield."

The final lining, cast-in-place concrete, is typically installed a minimum of 100 days after excavation. This two-pass system allows stress relief and swelling or time-dependent deformation of the rock mass to take place prior to installation of the final lining.

"As an alternative, the design team looked at the use of a single shield rock TBM with a precast concrete tunnel lining to mitigate certain risks associated with the two-pass system," he says.

The DRCW will be one of the first applications of precast concrete lining in Toronto's Georgian Bay shale. Each stage of tunnel construction presents unique challenges.

The Coxwell Bypass Tunnel is significantly larger in diameter and longer in length than tunnels historically constructed in the Georgian Bay shale of Toronto. On the Taylor-Massey Tunnel, the soft ground tunnel will cross underneath an existing sanitary tunnel, with under 2m of cover, and will require TBM operation at face pressures exceeding 5 bar. On the Inner Harbour West Tunnel, the potential exists of encountering a buried bedrock valley that could result in nonuniform excavation conditions for this segment of the project.



***Below:** The proposed tunnels and existing Coxwell tunnel*

ON LOCATION

The new system includes 22km of tunnels ranging in diameter from 4.4m to 6.3m. Over the length of the tunnel,

Contract packages

- Stage 1 – Coxwell Bypass Tunnel
- Stage 2 – Taylor-Massey Tunnel and Connections
- Stage 3 – Offline Storage Tanks
- Stage 4 – Inner Harbour West Tunnel
- Stage 5 – Tunnel Connections on Inner Harbour West Tunnel and Coxwell Bypass Tunnel.

Top: Artist's render of the waterfront project and facilities

Above: The Spadina WWF Connection

the geology and associated challenges change significantly, Cressman explains. Ground conditions include shale rock of the Georgian Bay Formation and soft ground soil consisting of glacial till, glaciolacustrine and glaciofluvial sand, silt and clay deposits.

The majority—16 km—of the tunnels is anticipated to be located in the shale bedrock. "The shale bedrock has a high horizontal-to-vertical stress ratio and is known to exhibit long-term swelling behaviour when excavated and exposed to fresh water," he says. "The vertical profile of the rock tunnel requires tunnelling through locations with reduced rock cover and has the potential to encounter several buried valleys consisting of soft ground soils.

The tunnel also crosses the historical alignment of the Don River (it was realigned in the late 1800s) in several locations.

The remaining 6km of tunnel is anticipated to be in soil. The soft ground section of tunnel is expected to be excavated through glacial till layers separated by interstadial deposits of sand, silt and clays. The glacial till layers are known to present hard and abrasive tunnelling conditions, while the interstadial deposits, present below the water table, have the potential to run into the tunnel face if not properly controlled during excavation.

"Another challenge is that the land use changes significantly along the tunnel alignment," Cressman says. "The tunnel moves from an industrial area currently undergoing rapid development to the high-density residential areas of downtown Toronto and the Lower Don River and then transitions to parkland in the upstream portions of the alignment along the Don River. The presence of diverse stakeholder groups has created unique challenges related to stakeholder engagement and coordinating and obtaining project permits and approvals."

The tunnel alignment has been selected to follow the Inner Harbour of Lake Ontario, the Don River and Taylor-Massey Creek to facilitate connection of the existing outfalls to the tunnel system (instead of discharging to the various bodies of water as is currently happening).

The system will convey flow by gravity to a new pumping station at Ashbridges Bay Wastewater Treatment Plant. The depth of the pumping station is governed by the hydraulic conditions and the availability of screens to accommodate sediment removal. "At the upstream end, the new tunnel must be able to divert flow from the existing Coxwell Sanitary Trunk Sewer into the tunnel," Cressman says. Within these criteria, the tunnel alignment and depth have been determined by considering a number of factors including cost, geotechnical risk, utility conflicts, constructability concerns and the hydraulic performance of the system.

The tunnel slopes were designed to maximize sediment transport characteristics through the tunnels and move sediment down the tunnel system to the new pumping station. The established slope places the tunnels at a relatively consistent and significant depth of approximately 50m. The vertical alignment of the tunnel was selected to reduce the number of buried valley crossings and ensure that utility conflicts were avoided.

The new tunnel crosses an existing water supply tunnel, which was constructed in 1929, in two locations. "The alignment was selected in coordination with a finite element analysis that was performed to ensure the risk of damage to the water tunnel had been mitigated to a very low level," Cressman says. "All these factors were considered while trying to minimize the long-term operation and maintenance cost associated with pumping from a significant depth."

TUNNELS AND SHAFTS

The Coxwell Bypass Tunnel and Inner Harbour West Tunnel will be excavated through shale bedrock of the Georgian Bay Formation. They are proposed to be constructed with a single shield rock TBM and lined with precast concrete tunnel lining.

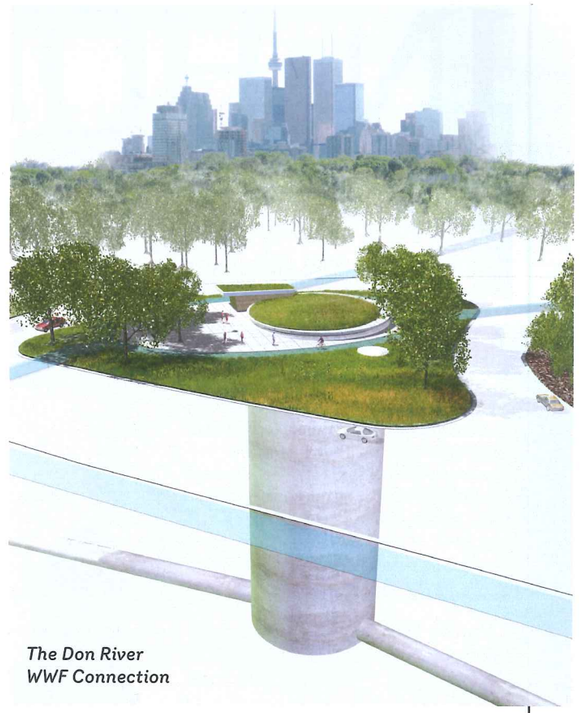
"This method was chosen to mitigate risks while crossing buried bedrock valleys, including the risk of encountering weathered bedrock or incurring significant ground water inflows or surficial soil deposits through buried valleys," Cressman explains.

The Taylor-Massey Tunnel will be excavated through Quaternary (surficial) deposits and will require use of a pressurized face TBM, either EPB or slurry. The tunnel will be lined with a precast concrete tunnel lining. He says, the use of a pressurized face TBM will eliminate the need for active dewatering and mitigate the risk of ground loss and surface settlement.

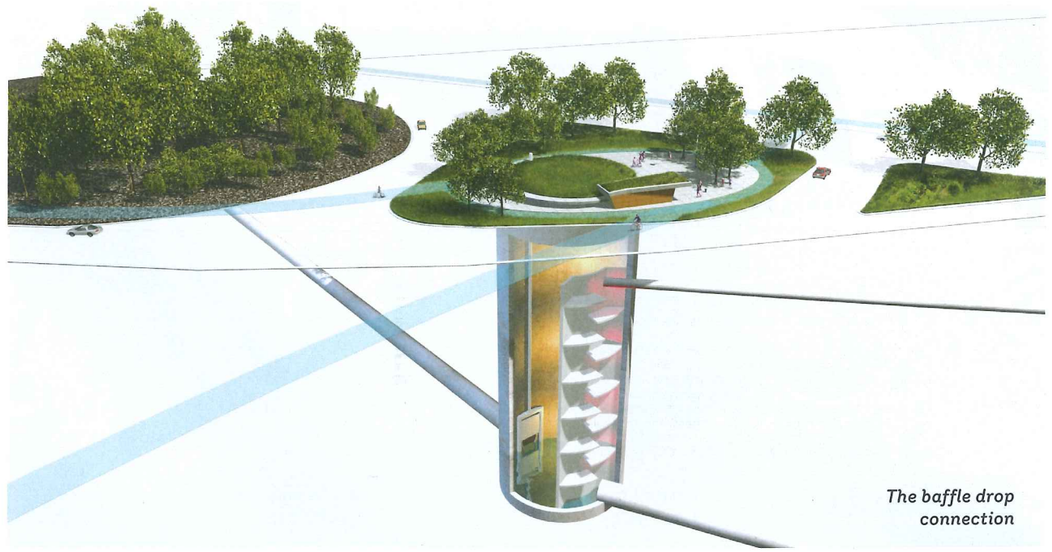
The proposed shaft excavation and support methods consist of impermeable support through the surficial soils to mitigate the use and impact of dewatering. The proposed impermeable support consists of either secant piles or slurry walls, depending on the depth of shaft.

"The impermeable soil support is to be installed a minimum of 3m below the soil rock interface and into good quality rock to cut off the ground water," he says. "Below the impermeable support, the use of welded wire mesh with rock bolts is proposed as the temporary rock support. The final structure of the shaft will use the excavation support lining as the outside form of the structure, which will eliminate the need for fill and provide the diameter required for hydraulic performance."

The project is currently scheduled to be procured in five stages: three separate stages of tunnel construction, one for wet weather flow connection structures and one to construct offline tanks and prevent flow surcharging north of the tunnel alignment (see box). The first stage of construction, the Coxwell Bypass Tunnel, is scheduled start prequalification in early 2017, with tender documents released to prequalified bidders in late 2017. The subsequent stages will be scheduled with available funding



The Don River WWF Connection



The baffle drop connection

IN HOUSE

The City of Edmonton is known as having one of the most unique utility departments across North America—with more than 40 years of experience and knowledge of tunnelling. **Nicole Robinson** looks at recent work for TBM refurbishment

SINCE ITS FIRST PROJECT in the 1980s, a Lovat 126 inch (3.2m) TBM has been working continuously in Edmonton on various tunnelling projects.

Recently, the City of Edmonton's tunnel group within the Drainage Design and Construction department and manufacturer Lovsuns refurbished the open mode TBM. It was re-designed to integrate a muck ring, pressure leaving gates, and a mixed face cutting head to bore in varying soft grounds, among other upgrades.

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

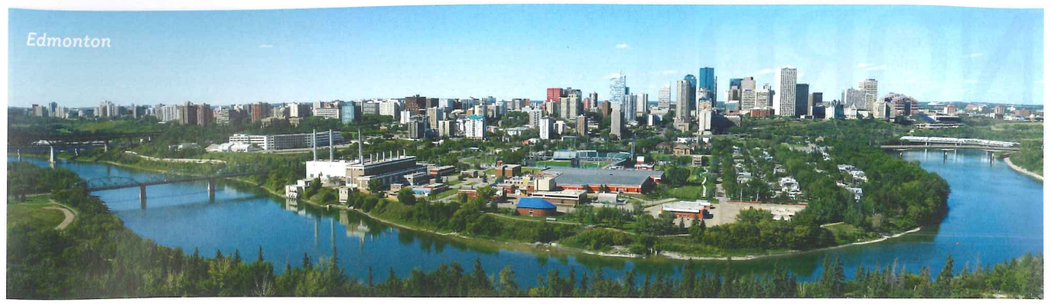
The TBM launched in May for the South Edmonton Sanitary Sewer Tunnel Project (SESS), Section SW4. It's one of four machines currently working underground in Edmonton, on projects constructed by the city's own in-house tunnelling group.

The Drainage Services equipment team started refurbishing TBMs internally almost two years ago, and their first TBM job saved the city CAD 400,000 (USD 304,000). Since completing that TBM they've done refurbishment work for a total of four machines.

SW4 begins at the end of an existing tunnel and as of this fall some 200m of the tunnel drive has been completed, says Darsh Nawaratna general supervisor, equipment (trades and shops) with the City of Edmonton. The length of tunnel is 1,528m and there are two intermediate shafts for ventilation and safety purposes during construction and for future sewer maintenance. The drive will be completed by the end of next year.

Refurbishment work took place in Edmoton except for

The TBM launched this spring



improvements to the cutter head, which Lovsuns upgraded. Dating back to the 1980s, the manufacuturer modernized cutting tools according to the project's geotechnical requirements and to create a more versatile TBM, says Sanjay Birbal, sales and parts refurbishment manager for Lovsuns.

"Previously the cutting head had no scrapers and an old style fishplate or centre cutter, and old spade gauge teeth," he explains. "We added a full face of scrappers, new conical gauge and spade tools and three modern, replaceable ripper teeth on the gauge, positioned on the outer end of the spokes."

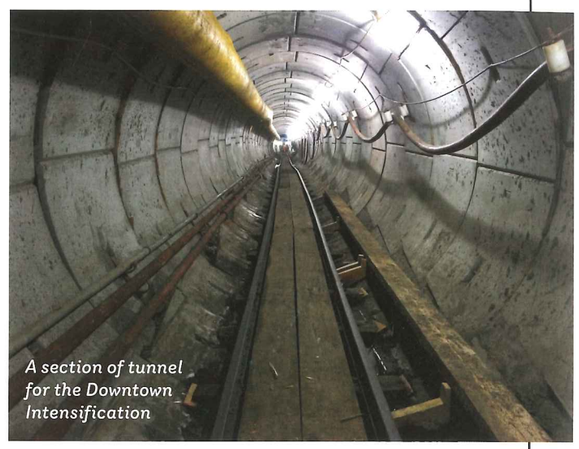
He adds, "since TBM launch in May, the TBM has been continuously mining with no issues and no cutting tool changes."

The city also has two TBMs deployed for the Edmonton Downtown Intensification project, which concerns stormwater. The total project length is 2,160m and the tunnelling group is using 100" (2.5m) and 102" outside diameter machines for this project and expects to complete the work by the end of next year.

The fourth, another 100" machine, is boring the NC 2&3, which is part of the North Edmonton Sanitary Trunk or NEST. "We have already started to do the first portion of this project, 385m, and the second leg of that project is going to be 2,300m long," Nawaratna reports.

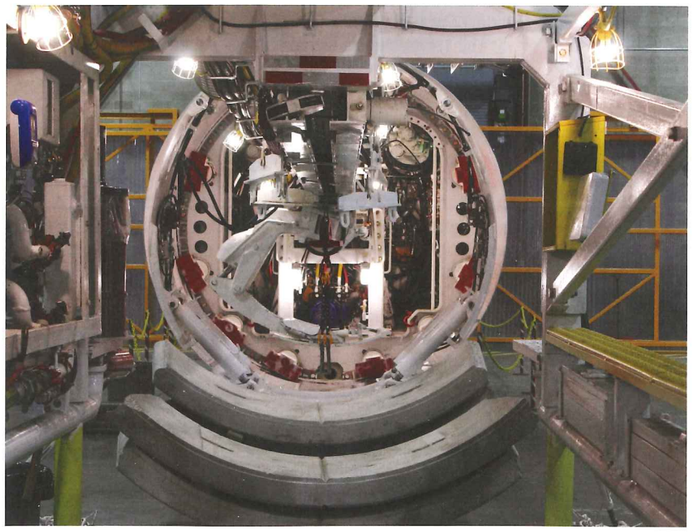
All four of the tunnels under construction start from and finish at shafts lined with rib and lagging. They are lined with precast concrete.

The City of Edmonton owns six TBMs with diameters ranging from 100 inches to 159 inches (4m). The tunnelling group says the reliability of these six machines will play a key role in successfully completing city's drainage tunnels—a city in which particular areas are seeing rapid population growth.



A section of tunnel for the Downtown Intensification

Below: ***The refurbished SW4 TBM*** *ALL PHOTOS COURTESY OF CITY OF EDMONTON*



As of April, the city's population has increased by more than 20,000 people since 2014, the city reports. Looking specifically to the areas served by the SESS a report by ISL Engineering found that population is expected to grow from approximately 25,000 in 2010 to at least 90,000 and possibly closer to 130,000 in 2025. ISL was retained by the City of Edmonton to update the implementation plan for the system, in addition to being the prime consultant to the city with SMA Consulting to provide value engineering and risk assessment services.

In addition to work for the projects underway the tunnelling group began moving into a new 50,000sqf (4,650sq.m) facility in spring 2014. TBM refurbishment work area comprises some 16,400sqf (1,500sq.m), with the rest of the shop dedicated to welding, general mechanics, electrical, a part store and a TBM. As of this April, the move is complete. Edmonton has five full time TBM technicians and one TBM hydraulic specialist. There are also four electricians, eight welders and six heavy-duty mechanics for TBM refurbishment works and other tunnel construction support services

NORDIC NEIGHBOURS

Tunnels & Tunnelling North America, official publication of TAC, looked at some of the projects underway in the member nations of the ITA's Nordic Forum. Reprinted here

THE TUNNELLING ASSOCIATION OF CANADA (TAC) is a member of the Nordic Forum, gaining exposure to unique and challenging projects in other forum countries. Membership is limited by geography and the forum meets one to two times a year at WTC and or at one of the participating nations.
TAC hosted the forum at its 2014 Conference in Vancouver.

Jason Mann, TAC regional director for Manitoba and Saskatchewan and a geologist at KGS, attended a Nordic Forum meeting in Iceland last year.

"There are quite a few underground challenges the Icelandic tunnelling industry encounters, and they seem to have a strong tenacity in seeing the projects through," Mann says. He notes the challenging geology and the industry's approach to drill and blast. "They encounter challenges and just do what it takes to push through it. Also, their tunnels can have seepage groundwater temperatures in the order of 60ºC—something quite unique and challenging relative to staging the work, and staging personnel."

Iceland boasts about 150km tunnels, mainly for roads and for hydro power, and this works out to be about 0.5m of tunnel per person.

***Above:** A rendering of the tunnel connecting Denmark and Germany* PHOTO: FEHMARN A/S

***Below:** Consolidation grouting at east side weak zone of Vadlaheidi* PHOTO: ICELANDIC TUNNELLING SOCIETY

NORDIC UPDATE

Iceland

Road tunnel projects are ongoing with lengths between 7 and 8km. Hydro power projects are also underway requiring water tunnels and an underground powerhouse. In the near future two more road tunnels are on the horizon, starting before 2020.

Denmark

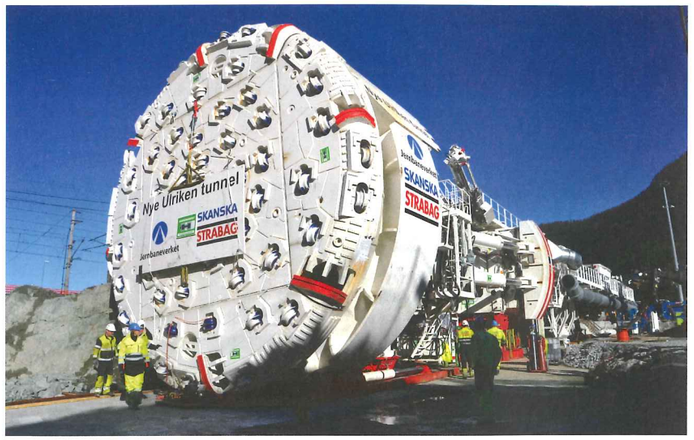
Demand for tunnelling is increasing, and excavation of metro tunnels in Copenhagen will continue. The city's new circle line is a 15.5km twin tunnel that will, as the name suggests, add a circular transport route around the city, connecting with the existing metro lines. The new system, which is due to open in 2018, will have 17 new stations.

The 18km-long submerged tunnel between Denmark and Germany, Fehmarnbelt, reached the end of its public consultation period on August 26. The German section must be approved by German authorities before construction can get underway while the Danish section is already approved. Femern A/S signed conditional contracts this summer with the consortia chosen to construct the tunnel. Femern Link Contractors, consisting of Vinci Construction Grands Projects, Per Aarsleff Holding, Wayss and Freytag, Max Bogl, Bachy Soletanche, CFE, Bam Infra, Bam International and Dredging International, secured the Tunnel North Contract; Tunnel South Contract and Tunnel Portals and Ramps Contract. Fehmarn Belt Contractors (Boskalis International, Van Oord Dredging and Marine Contractors, Hochtief, and Zublin) have the Tunnel Dredging and Reclamation contract. Cost estimates suggest the project will be at least USD 8bn.

Norway

About 75 tunnel projects are ongoing with more to start soon. In 2015 statistics show the country excavated a total construction volume of 7 million cubic metres of solid rock.

The largest on-going project is the 20km-long, twin tunnel Follo rail line in Oslo. Four Herrrenknecht 9.96m-diameter double



shield TBMs are being deployed, with the first expected to start boring in September by a contractor JV of Acciona Infraestructuras and Ghella. Outside Bergen there is the E16 highway rebuild, which will include about 32km of new tunnels. There is also the upgrading of the Ulriken railway line with about 7.8km of new tunnel mostly excavated by an open TBM.

Norway is also hosting the 2017 WTC in Bergen June 9-15.

Sweden

In Stockholm there is the City Bypass (Forbifart Stockholm), a series of underground roadways with about 16km of tunnels. Contractors for tunnel work include Svevia, Hochtief, Bilfinger Berger, Skanska, Züblin-Pihl, PEAB, Veidekke, Oden and Bravida and Tunnelentreprenader AB.

For rail, the USD 2.4bn Stockholm City Line, or Citybanan, comprises at least 6km of tunnelling and two underground stations. The line is scheduled to open in 2017. Atkins Sweden, as part of a consulting team of ÅF, Rejlers and Tyréns has been commissioned to carry out the detailed design of the system. Contractors include , Joint Venture Söderström – Züblin (and previously Pihl & Søn), NCC, Bilfinger, Strabag, Züblin and PEAB. Designers are Cowi, WSP, Sweco/Grontmij, WSP, Ramböll, Ramböll/ELU and Cowi/Centerlöf & Holmberg.

There is also a 14km tunnel for high voltage cable on the

***Top:** Scanning detonators in preparation for blasting on Stockholm's City Line* PHOTO: MIKAEL ULLEN

***Above:** The TBM for the Ulriken tunnel project in Norway*

***Right:** The TBM launched this summer for the Shieldhall Tunnel in Scotland* PHOTO: SNS PHOTOGRAPHY

design board, and in Gothenburg 6km of tunnel is on the design board. Railway plans between Stockholm and Gothenburg also include a lot of tunnels.

Scotland/UK

The Shieldhall Tunnel will be Scotland's largest wastewater tunnel at 4.7m in diameter and 5km long. It will form part of the biggest upgrade of Glasgow's wastewater network in more than a century. Scottish Water awarded a JV of Costain/Vinci the contract to build the tunnel, and they are using a Herrenknecht TBM with precast rings supplied by Buchan Underground. Completion is anticipated in early 2018.

Further south, the Thames Tideway project will be the largest infrastructure project ever undertaken by the UK water industry, with a main tunnel 25km long, shafts up to 72m deep and numerous connecting tunnels. The rail mega projects Crossrail Two and High Speed Two seem almost a certainty, valued at around USD 30bn and USD 60bn each. Additionally a 4.1m-diameter, 37km tunnel has been confirmed to transport minerals from a new polyhalite mine in North Yorkshire to the Port of Scarborough.

Finland

Tunnelling is continuously ongoing, so much so Finish tunnelling companies have enough projects and have not gone much abroad for construction projects. In Helsinki the City Center link tunnel of about 6km is in the planning stage.

In January political leaders in Estonia and Finland signed a memorandum of understanding stating the intention to improve connections between the two countries—including a long-mooted tunnel between the cities of Helsinki and Tallinn. A subsea tunnel would reduce travel time from the current two-hour ferry ride to 30 minutes. Additionally, plans to link Tallinn to the European high-speed rail networks could be extended to Helsinki. A recent pre-feasibility study suggested that the tunnel could be constructed for less than USD 14bn. EU money is required for further studies

DUBAI WATERWORKS

Al Naboodah has been engaged to divert utilities in advance of the Dubai Water Canal project. The job called for microtunnelling, as well as HDD close to piling work

THE NEXT BIG THING IN DUBAI, the Dubai Water Canal project is currently underway and is to include the construction of a 3km long waterway, as well as thousands of residential and commercial units and public infrastructure along its banks.

Al Naboodah Construction Group (ANCG) was hired to divert utilities on a section of the project. The company accomplished that task with horizontal directional drilling (HDD) for the cable ducts and microtunnelling for the glass reinforced epoxy (GRE) water lines, which cannot be installed by HDD. For the HDD work, ANCG completed 24 bores, totalling approximately 7,315m, and often worked within small footprints in areas bustling with activity. The HDD rig manufacturer was Vermeer.

The microtunnelled work comprised nine crossings spread over two locations. The first location required 156m of tunnelling, with the following diameter drives: 1 x 1200 mm (1,200 mm GRE water main) and 2 x 1000 mm (2 x 300 mm GRE water main in each 1,000mm sleeve). The second location required 142m of tunnelling with the following diameter drives: 1 x 1200 mm (1200 mm GRE water main) and 2 x 1,200 mm (2 x 300 mm GRE water main in each 1,200 mm sleeve) and 3 x 800 mm (2 x 630 mm irrigation main and 1 x 600 mm water main in each 800 mm sleeve). The MTBM manufacturer was Herrenknecht. It supplied AVN 1200 and AVN 800 machines.

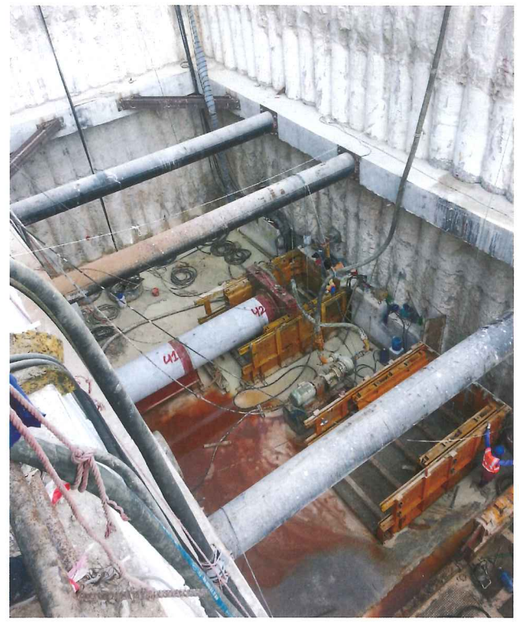
"The HDD work was in a tight corridor with multiple crossings next to busy roads," says Alan Welch, general manager (Civil) for ANCG. "And in two locations there was ongoing piling work for the bridges across Dubai Canal, giving us an additional challenge due to all the vibration caused by the sheet piling hammers.

"With the entry and exit sections (45 metres on both sides) of the drilled bores being in soil with a SPT value ranging from 8 to 20 the risk of collapse of the hole was always present during the piling works. By using a top quality bentonite with a high viscosity the bores were stable enough throughout the piling works." The microtunnelling was not hampered in any way by the piling.

DUBAI BOOMING

The construction business has been good in Dubai in recent decades. The city has grown greatly physically and culturally since oil was discovered there in the 1960s. Dubai is now widely considered a global city, meaning it plays an important role in the worldwide economic system. Its population in 2015 was 2.45 million people, a 184 per cent increase since the start of this century, according to the Dubai Statistics Centre.

The Dubai Water Canal project could be completed as early as 2016. The actual canal is to run from a central business district to the Persian Gulf. It is to range between 80 and 120 m in width and be 6 m deep. Media reports say that, counting commercial, residential and public space, the project will cover 4.68 million sq m. It will include more than 5,300 residential units, nearly 1,000 hotel rooms, several hundred retail outlets and restaurants, 60 marinas, a three-level mall with a rooftop park, new bridges, and walking and cycling paths.



Above: The launch pit for the Herrenknecht MTBM

ANCG was charged with installing conduit for several different utility lines – HDPE, PE 100 and SDR 11 – in the project. It used HDD for power and telecommunication cables and irrigation lines. It used microtunnelling for water mains.

ANCG had to complete 24 crossings averaging 305m in four locations. Their work was vital for the timeline of the overall project because installations at two of the locations had to occur before bridges, which were important to relieve traffic issues, could be built.

"Bridges were planned on top of the HDD route, so it was critical those locations were completed as soon as possible," Welch says.

TIGHT SPACES

Another challenge was the small footprints the crews had to work in and narrow windows downhole they had to place the utility lines.

"The utility corridor was extremely narrow," Welch says. "At times, up to eight crossings had to be squeezed into a corridor only 5 m wide."

The crew used an optical gyro steering tool to help achieve the accuracy they needed with the Vermeer D300x500 Navigator horizontal directional drill.

"Considering the limited space available on the sites, the Vermeer D300x500 was the ideal rig for us as it is an 'all in one' unit, whereas other rigs of its size have separate control cabins and power packs and require large cranes to be positioned," Welch says.

Ground conditions consisted of medium-dense to dense sand for the first 14 m that registered N-values ranging from 18 to 35 on the standard penetration test. Below that was sandstone that Welch describes as "weak."

The HDD crew used a 216mm tricone bit and a 171mm mud motor on the pilot bores. The depth of each crossing was determined by how far under they needed to be at that section of the future canal, which was yet to be dug. The deepest crossing was 20.5m below the existing ground level. The shallowest was 12m.

Depending on the bundles being installed, they used back reamers of 457, 508, 864 and 1,067mm in diameter.

For drilling fluid they used bentonite with some soda ash to increase the pH level of the makeup water. No polymers were used. ANCG used a Vermeer R300 reclaimer, a Vermeer SA400 high-pressure mud pump to deliver a consistent flow of drilling fluid and had a Vermeer SA300 mud pump as a backup. They also used three separation plants to process slurry.

"Reclaimers are used on all our HDD projects to reduce cost and environmental impact," Welch says. "On this project, excess bentonite from one location was reused at the next location. That meant we only had to dispose of bentonite once, which was at the end of the project."

LOTS OF MOVEMENT

ANCG took an innovative approach to this job by drilling all of the pilot bores at a single location first before back reaming and doing the product pullback. They had a total of 24 crossings at four locations. So, if there were six crossings at one location, the crew would drill the six pilot bores, and then pull back the product. That decision was made to limit the time, and therefore expense, that the gyro steering tool was onsite.

The pilot holes stayed open between seven and 30 days, with an average of 14 days. The drilling fluid was mixed to ensure the holes remained open for extended periods, and if any fluid loss was observed, more bentonite was sent downhole. ANCG accomplished this without any problems.

Welch explains the unusual length of time the bores were kept open: "it is common practice to start back reaming/pulling after completion of the pilot drill and execute crossing one after the other but due to the cost of the Gyro steering tool the decision was made to drill all pilot holes at one location first."

Welch says the manoeuvrability of the self-contained Vermeer rig proved to be a big asset. He says a trailer or rack-mounted rig usually takes a full day to move and set up, but his crews could get the D300x500 set up within one hour.

"The total project took us 170 days," he says. "We had to move the rig 48 times – once for each of the pilot bores and then again for the product pullback – so if we had used another rig it would have taken us at least 48 more days to complete the project."

That helped ANCG play its part in the construction of what will soon be another iconic project for Dubai. Welch concluded: "Our biggest challenge was the limited time slots given for each location but looking at how smoothly the job went we would not change our strategy if we had to complete it again.

"We finished each of the four locations in four to five weeks depending on the number of crossings. Work commenced in October 2014 and was completed in July 2015. After finishing one location we did not have immediate access to the next one"

Both: Vermeer D300x500 horizontal directional drilling rigs

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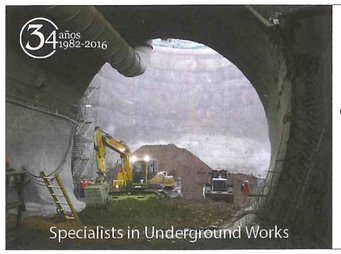

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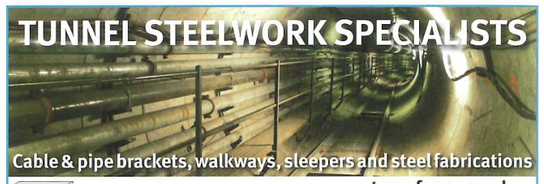

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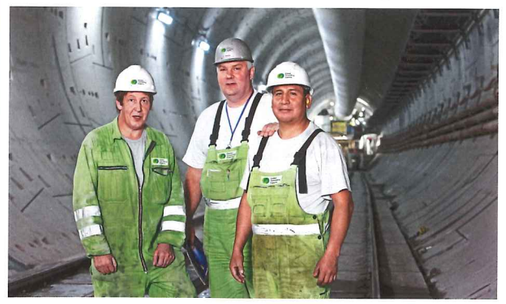

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BTS CORPORATE MEMBERS

What's on

2016

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

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

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

Architex 2016
15-16 November 2016
Liverpool, UK
ArchitEx brings together architects, specifiers, building designers, developers, planning officers and suppliers together in a regional setting to explore local opportunities, debate topical issues, learn from national and international case studies, discuss the latest design trends and network with new contacts.
www.architexevents.com

TBM Digs
16-18 November 2016
Istanbul, Turkey
Turkey has a great potential for tunnelling work, and in the near future the country is expecting to see upwards of USD 35bn of investment in the underground. The Turkish Tunnelling Society is also rapidly expanding its membership.
www.tbmdigsturkey.org

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

Bauma China
22-25 November 2016
Shanghai, China
Bauma China is Asia's largest and most important event for the construction industry. It attracts international buyers – a fact that guarantees a high return on your investment.
www.bauma-china.com

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

BTS Health and Safety Course
28-29 November 2016
London, UK
The BTS runs a two-day annual Underground Health and Safety Course. Booking is open on the website.
www.britishtunnelling.org.uk

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

2017

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

4th Brazilian Tunnelling Congress and Latin American Tunnelling Seminar
3-6 April 2017
Sao Paulo, Brazil
The fourth edition of the Brazilian Congress of Tunnels and International Seminar: "Latin American Tunneling-LAT 2017", will take place in parallel to the 9th International Symposium on Geotechnical Aspects of Underground Construction in Soft Ground- TC-204 ISSMGE
www.tuneis.com.br

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

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

World Tunnel Congress 2017
9-16 June 2017
Bergen, Norway
The theme of the 2017 World Tunnel Congress is 'surface problems - underground solutions'. The Norwegian tunnelling industry produces tens of kilometres of drill and blast tunnel every year through the complex topography of this Nordic country
www.wtc2017.no

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

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

Stuva Expo 2017
6-7 December 2017
Stuttgart, Germany
The 2015 trade fair accompanying the Stuva conference exceeded all expectations. With 1,850 conference delegates and more than 550 trade visitors, around 2,400 visited in 2015.
www.stuva-expo.com/en/

2018

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

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

2019

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

The British Tunnelling Society

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

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

The BTS Christmas debate
8 December 2016
The annual BTS Christmas debate takes place this year on 8 December. Two sides meet to debate a topic apposite to tunnelling. After two rounds of discussion, the vote is put to the audience and a decision is made. Past topics have included "further development of SCL for complex urban tunnels is the best way forward for our industry", and "regulation and the accompanying compliance culture is stifling Innovation and Creativity within the tunnelling industry".
Speakers: TBC
Please note that this event takes place on the second Thursday of December

The Harding Memorial Lecture: Tunnelling impact assessment for utility pipelines and tunnels
19 January 2017
An important consideration when planning and carrying out tunnelling works is the impact that those works may have on Third Party assets, particularly in cities. Damaging ground movements and loads may be caused by the tunnelling itself and/or by associated works for shafts. The impacts of tunnelling on buildings throughout the world have been widely reported but the impacts on utility apparatus have not received such detailed and extensive attention in the literature. The principal purpose of this lecture is to consider strategies and methods of impact assessment for utility pipelines and tunnels. The content is informed by numerous investigations into pipeline failures and consideration of the geo-environment of pipelines in cities which may render conventional analyses unreliable or even intractable. The lecture will discuss the current, mainly analytical, approaches to the problem and suggest other more broadly risk based methods which may be considered for future application. The emphasis will be on simplifying the assessment process to reflect the uncertain condition of the pipelines and other relevant factors but retain the asset protection essential to utility providers.
Speakers: Barry New, Geotechnical Consulting Group

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

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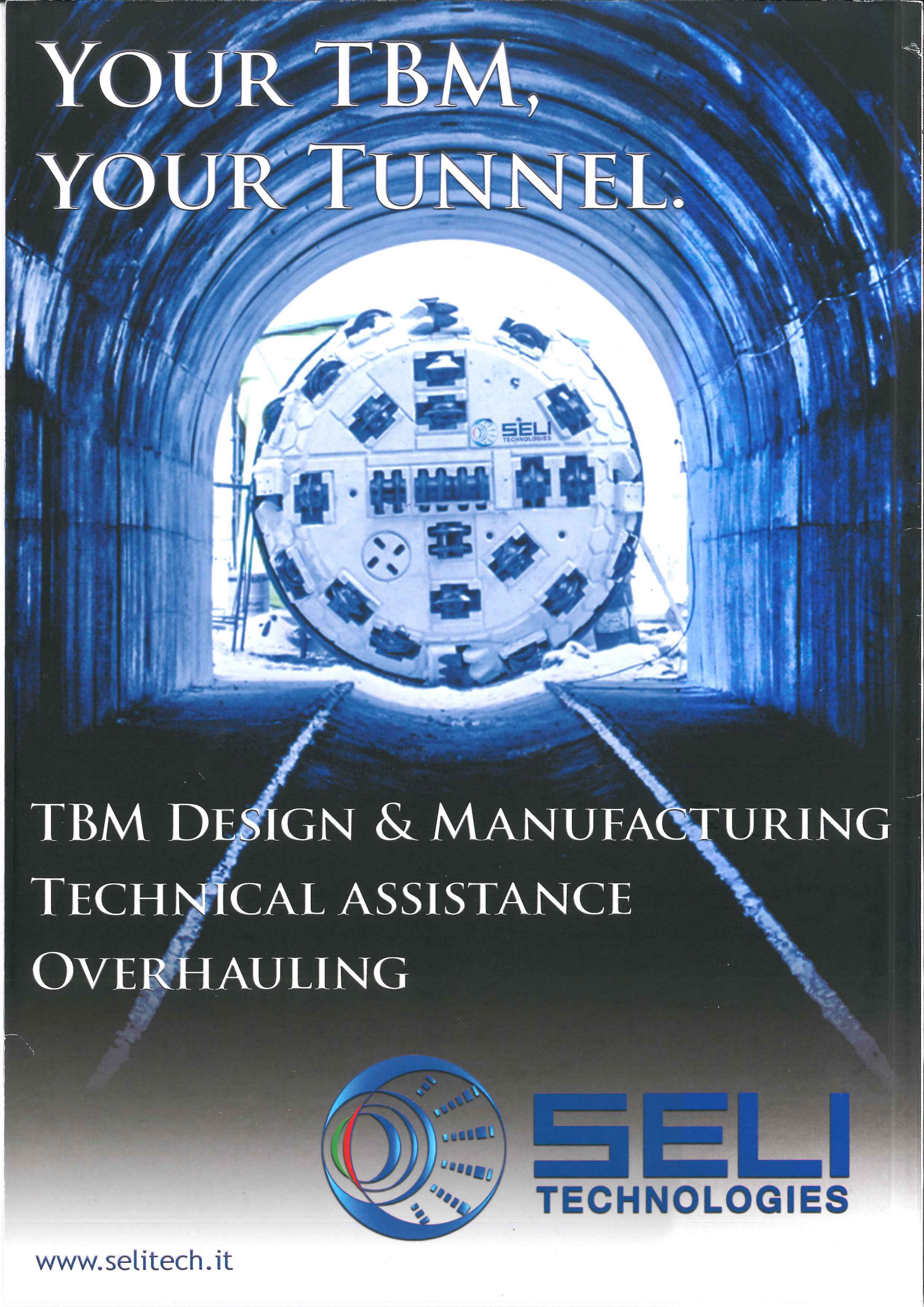

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