TUNNELTALK ANNUAL REVIEW 2019

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TunnelTalk

10th ANNIVERSARY

Direct by Design

Annual Review

2019

Into 2020

Annual Review 2019

This edition celebrates the tenth anniversary of the *TunnelTalk* Annual Review. As a compilation of the major events of the past 12 months, this issue spans the successes and developments of 2019 and the pandemic disruption of early 2020. For everyone, in business, and in their personal lives, the Covid-19 coronavirus pandemic has changed all that was considered normal prior to the end of 2019. Conferences, events and international travel have been cancelled and lockdown expanded to include shutdown of construction sites, suspension of local transportation services, and work-from-home orders leaving offices and businesses closed and the streets and cities silent.

But adaptation soon mobilised. Meetings and conferences moved on-line, public transport for essential service workers resumed, exemptions were granted to construction sites to continue project progress as vital national infrastructure works and we all have become accustomed to social distancing and wearing face masks.

For *TunnelTalk*, working in a virtual office environment has been the norm since launch of the magazine in 2008 and the adjustment has been readily accommodated. Changed family responsibilities have required changes to individual work schedules but the magazine has remained on its weekly publication schedule and distribution of the news Alert every Thursday has continued without fail. Cancellation of international conference gatherings shifted the publication date for our Annual Review, but its tenth edition was never in doubt and is available now for free distribution and download as a digital edition and in hard copy for purchase and posting.

The special 10th Anniversary pages celebrate the years of service by the magazine and the dedication of its team. It marks a journey through time for the major projects of the last 10 years, as well as the principal events, company evolutions, outstanding individuals and leading technical developments of our remarkable underground design, construction and operation industry. Enjoy the review and your part in the process! ■

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Unprecedented times

Shani Wallis, *TunnelTalk*

At the end of 2019, the hope for 2020, at the start of the new decade, was for a sense of 'getting back to business' to take hold and for a longer-term view to become the focus for the global perspective. Smooth sailing into the 2020s was the title of our opening article for the start of the decade. Who could have predicted that the global focus would be the fight against a virus pandemic. Looking back on 2019, it was smooth sailing by comparison.

Global restrictions imposed by governments to control the coronavirus pandemic threw 'business as usual' into complete disarray. Job sites were closed down; events were cancelled or postponed; offices, schools and universities were closed; and lockdown became the norm with everyone who could, working from home.

On going to press, controlling the pandemic remains the global focus, with the social and economic consequences beginning to be assessed and the dilemma of how to come out of the social isolation and lockdown being faced. For civil engineers, topics beginning to engage the minds centre on how society will change and what the future will look like. With schools and offices closed and cars parked, the air is much cleaner and the burning of fossil fuels dramatically reduced. With the use of trains and metros also much restricted and all aeroplanes but a few grounded, will the internet remain the virtual highway for the future for schools and businesses and what will we do with the vast expanses of roads and highways and runways in the engineered future?

Ironically, at the end of 2019 the question was posed: If we could increase productivity and reduce the cost of excavating underground space significantly, and if scope was not an issue, where would it be sensible to build underground facilities and tunnels? The list grew and grew (Table 1) and others were suggested to ponder. Perhaps some of these will provide direction for the future and help shape society on the journey ahead.

Earthscrapers: Build down instead of up. There are many different concepts being promoted for creating underground living and working spaces and for facilities such as sensitive laboratories; underground farming; underground cemeteries, and underground long-term storage banks. ITACUS, the ITA Committee on Underground Space of the International Tunneling and Underground Space Association, is promoting more imaginative and feasible concepts for the use of the underground environment.

Underground homes: In very hot and very cold climates the underground temperature is naturally stable and provides a comfortable environment for human habitation and activity. Existing examples include the underground homes and hotels in Coober Pedy, South Australia, the networks of underground shopping malls with direct access to metro stations and car parks in Helsinki and Montreal, and the retail spaces built into all the underground stations of the Hong Kong Metro.

Underground car parking garages in urban areas: Parking on both sides of narrow streets in urban areas is a serious issue and there are opportunities of having the entrances to underground garages in local parks with the exit at the far end for one-way traffic with a parking space under each house and linked via an elevator or a stairway into the home or the garden.

TBM manufacturer CREG has developed a rectangular machine for excavating such underground car parks, erecting precast concrete elements behind. The concept was an entry in the ITA Awards of 2019 in the Innovative Underground Space Concept category.

The parking garage for the Sydney Opera House in Australia is an example of one-way traffic through a garage, parking on the diagonal, and driving down through the helix to come up and out in the same direction of travel.

More undersea links: Narrow channels remain barriers to connectivity throughout the world. Immersed tubes and deep undersea TBM and drill+blast links are considered and planned for many. Other suggestions include a road connection for the Channel Tunnel; more links under the Bosphorus, where the bridges and the Eurasia double deck highway tunnel under the strait remain congested, and where plans for a mega bored tunnel for road and rail are being considered; fixed links from mainland to islands in the Mediterranean. The concept of the floating tunnel for deeper water crossings awaits development of a prototype project along with the Trans-Atlantic hyperlink floating tunnel concept, which has been a vision for several decades.

Table 1. Start and construction of an underground and tunnel excavation wish list

Country	Tunnel	Length	Purpose
Spain to North Africa	Gibralta crossing	40km	Rail
China-India	Link under the Himalayas	Several of 20km and more	Rail
USA - Russia	Link across the Baring Straits	90km	Rail
Norway	Ship tunnel (see p44)	1km	Canal
Norway fjord crossings	Floating tunnels to cross deep fjords	5km and more	Road
Canada	Vancouver to Victoria Island	Up to 26km long immersed tube	Road
Eire to UK	Dublin to Anglesey	100km	Road
England to Northern Ireland	Blackpool to Isle of Man to Belfast	100km + 60km	Road/rail
UK	Gosport to Isle of Wight	6km	Road
UK	A link for the M25 Jn5 to M1 motorways directly under London	60km	Road
Sweden-Finland	Stockholm to Turku (via Aaland)	100km	Rail
Channel Islands-France	Guernsey-Jersey-France	20km	Road/rail
Japan-Korea	Undersea link	200km	Rail
Russia-Sakhalin Island possibly on to Japan	Undersea link Undersea link	8km 43km	Road/rail Road/rail
India-Sri Lanka	Undersea link	25km to 50km	Rail
Argentina-Chile	Tren a las Nubes - Train to the Clouds	Several of various length	Rail
Argentina-Chile	Bioceánico Aconcagua	52.5km-long twin-tube base tunnel under the Andes	Rail
Habitation of the moon	Underground space	Caverns	Habitation and storage
CERN Geneva	Future Circular Collider (FCC)	100km	Nuclear physics
Hyperloop developments	Intra-city people movers	Various	Ultra highspeed travel

inspiring futuristic solutions

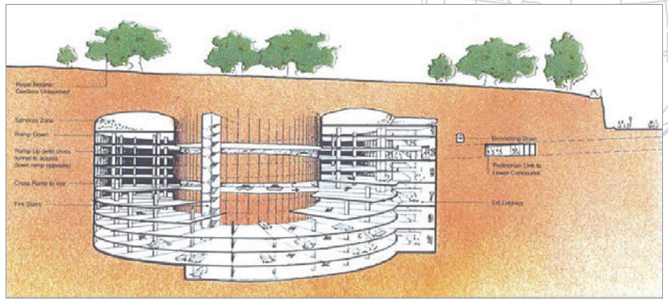
More high-speed rail worldwide: High-speed rail, travelling at 200km/hr, is a quick and more time and energy efficient alternative to travelling by air or by car for journeys of up to 500km. That distance is greater with greater speeds on maglev or hyperloop systems.

More underground metros: A rule of thumb often quoted is that an underground mass transit system is needed for cities of more than 1 million population. Given that criteria, there is a lot to do, and that is before considering the tremendous amount of work needed in cities of both more, and less, than 1 million for sewerage and water supply in developing countries.

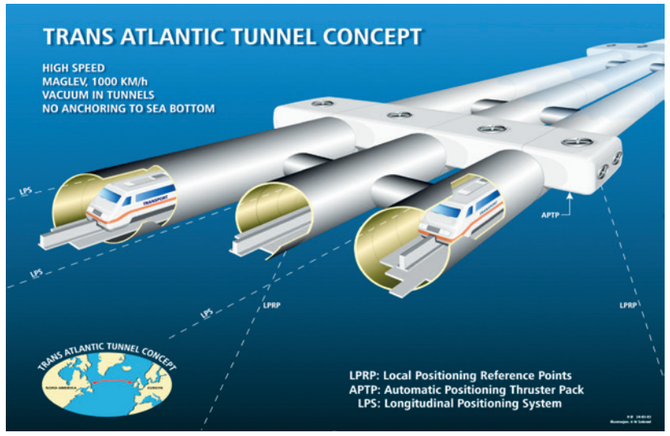
Tap the icecaps and glaciers: Harvest the melting of iceflows and glaciers and hold the fresh water in underground reservoirs and delivery systems, rather than waste it into the sea.

More hydro schemes: Use fresh water for multi-purposes and help reduce carbon emissions by increasing hydro energy generation as the environmentally responsible alternative. On another water related theme, have everyone buy quality drinking water in bottles and turn current fresh water networks into good quality, but less expensive, grey water quality for flushing toilets, watering gardens, washing cars, washing clothes, and everything but drinking and cooking.

Underground high voltage electricity cables: London leads the way with hundreds of kilometres of high voltage cable tunnels under the city (see p49). TBM manufacturer Herrenknecht won the award for innovation at the *bauma* trade show in Munich in April 2019 for its development of high-speed micro machines to create the underground links for carrying wind farm cables from the North Sea where it is generated, to the south of Germany where it is needed (see p88).



Double helix for one way travel through the Sydney Opera House underground car park



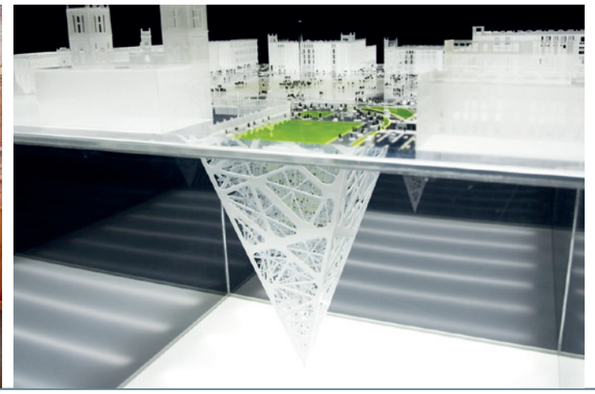
Futuristic concept for high-speed trans-ocean travel

Create more multi-use underground infrastructure: Examples of such infrastructure includes the SMART tunnel in Kuala Lumpur that is both a stormwater conduit and a double deck highway for when the stormwater facility is not needed; the water, gas, sewer, ground water conduits under Ashgabat, Turkmenistan; and large diameter TBM tunnels to accommodate both road and metro links in the same tubes. More stormwater facilities that could have a SMART tunnel concept are needed to protect sinking cities including Jakarta, Manila, Mexico City, Bangkok and many others.

Nuclear waste: Progress - with urgency - the desperate need for viable, safe, long long-term disposal or storage of low-, medium and high-level nuclear waste. This should be a universal imperative rather than a national issue to solve. The engineering industry is prepared and able to build such facilities. It is the political will and responsible leadership that is lacking. Another suggestion is to build nuclear power reactors underground in closed, contained environments. Caverns large enough for the purpose already exist in the impressive scale and excavation of hydro power machine halls.

Underground living in Coober Pedy, Australia

Build down rather than up in dense urban and city environments



Replace elevated highways and metros underground: As elevated highways have been famously replaced underground in Boston and Seattle, so too can others around the world. The Cahill elevated highway that ruins the Sydney foreshore is one or many examples. The Hammersmith flyover in London should have been a fly-under from the start. Elevated reaches of metros around the world could now go underground and free up highly valuable urban and city land space.

More reservoirs for big cities: Supply of water to cities is a constant forecast crisis. New reservoirs to hold more reserves and capacity will have to be underground as no-one wants them taking up open green space. Alternatively more distant reservoirs will need underground conduits to convey the water to city distribution networks.

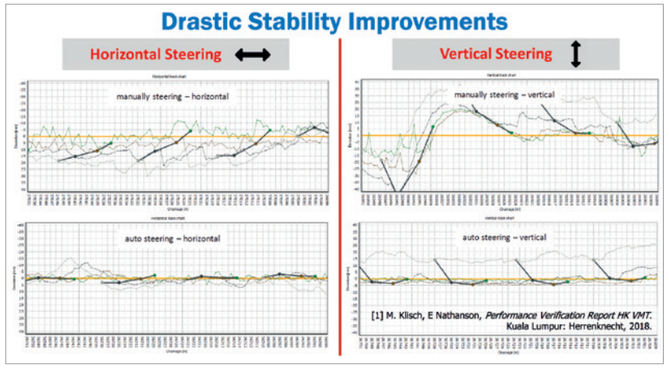
Quarries and mines: Ban all open cut and strip mining of the landscape and put all quarrying and mining underground. Use worked out underground mines for landfill rubbish disposal and deposits for tunnel project muck.

Links to offshore oil fields and gas wells: Engineers in Norway are studying the feasibility of such undersea fixed links. Tunnels could also bring in electricity cables from ocean wind farms and tidal energy generators or from stations where sea water is converted to hydrogen for energy generation.

Remove all level crossings: Grade separate road, rail and pedestrians to resolve these major safety hazards. Do the same for road and highway intersections to avoid the long, air polluting idling at stop lights and multi-lane intersections.

Ban open cut metro station construction: Mined construction of stations and running tunnels without disrupting the surface of the city has to be the way for underground station construction.

For just about everything that can be on the surface, there is an underground alternative. Productivity; speed of construction; difficulty of dealing with the ground as the host medium; cost; risk; willingness; social negatives; physiological problems of being underground; are all against these great ideas.



More precise steering by the autonomous TBM system

Industry Feedback

From: Michael M

I thoroughly enjoyed reading this piece and in the list of major projects in construction, there are a few in Europe that warranted a mention. First the Grand Paris Express: Comprising 200km of new metro with 68 underground stations, requiring +/-30 TBMs. Large portions are already under construction with many more contracts to be awarded and started this year (2020). Secondly, the high speed rail line between Lyon, France and Turin, Italy (TELT). The four contracts for the 57km twin tube baseline tunnel under the Alps went out for requests for proposals in early 2020.

Keep up the great work!

From: Siba Prasad Sen, India

To add to the wish list is a major highway tunnel through the formidable Western Ghats mountain ranges on the route west to Mangalore between Bangalore and Chennai (Fig 1).

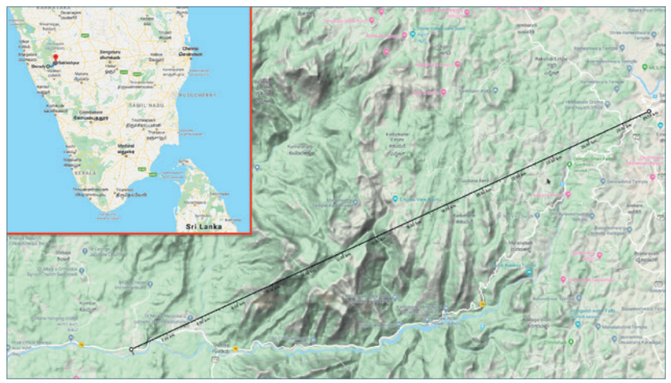
Back to reality

While it is engaging to consider the possibilities, the exercise is based on the premise of increasing productivity and reducing the cost of excavating underground infrastructure and here, a new exercise could be staged. How can we increase productivity and reduce costs? There are several studies underway worldwide to address these conundrums from a geological, technical, mechanical, logistical, contractual, environmental and political point of view with several ideas and concepts already in prototype or practice.

The harnessing of big data in BIM systems and the built-in monitoring of smart infrastructure are two examples. Others include the digitisation of machines and the development of more sophisticated robots. A team of engineers engaged by MMC-Gamuda on the Line 2 of the Klang Valley MRT project in Kuala Lumpur are leading the way in development and application of the first autonomous TBM system in operation, a development that was the clear winner of the New Technology and Innovations category of the 2019 ITA Awards (see p92).

So the future remains positive and engaging, with warnings and lessons to learn from past mistakes to keep the industry on track and progressing. One sober warning delivered in 2019 was at the WTC World Tunnel Congress in Naples, Italy, when Petro Salini, CEO of international contractor Salini Impregilo, stated in his keynote address that continuing attempts by owners to shift risk onto contractors who are bidding with ever decreasing margins, will lead to "extinction" of contractors (p8). There is no point in having bright, imaginative engineers designing the infrastructure of the future if there are no contractors with the courage and expertise to bring it to reality. ■

Fig 1. Proposed Western Ghats underpass: the road tunnel of 29km being considered will be challenging work due to the elevation differences and the prevailing geology. It has been discussed for some time and perhaps this decade is the decade in which it will advance



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New era begins for ITA at WTC 2019

Shani Wallis, *TunnelTalk*

The first woman president and the first president from China was elected to lead the International Tunnelling and Underground Space Association (ITA) for the coming three years during the 2019 World Tunnel Congress at its 45th Annual General Assembly of the Association in Naples, Italy

In a close result, the 78 Member Nations of the Association voted 30 to 32 to elect Jenny Yan of China, with Eric Leca of France proving a formidable fellow candidate. Yan takes over from President Tarcisio Celestino of Brazil and is joined by four new Vice Presidents with Lars Babendererde (Member Nation Germany) as first Vice President; and Randy Essex (USA), Arnold Dix (Australia), and Giuseppe Lunardi (Italy) as co-Vice Presidents. Newly elected members of the Executive Council are Jamal Rostami (Member Nation Iran); Abidemi Agwor (Nigeria); Hamdi Aydin (Turkey); Choi Hangseok (Korea); Jeyatharan Kumarasamy (Singapore); and Andres Marulanda (Colombia).

At the 2019 General Assembly session, Mexico was elected as host of the WTC and ITA General Assembly in 2022 at the resort of Cancun, gaining the majority vote from competing host Member Nation India and its proposed venue in Goa. Cancun, Mexico, might be expected to be a more popular choice, but India undoubtedly presents a greater need for underground infrastructure as the nation addresses urgent developments for city sewers, water supply lines, metros, hydro energy, intercity highways and railways, and irrigation networks. The WTC 2020 in Kuala Lumpur, Malaysia, has been severely disrupted by the coronavirus pandemic with most looking forward instead to the 2021 WTC to convene in Copenhagen, Denmark in May 2021.

Additional business of the ITA at the 2109 General Assembly included:

- Approval of three new Member Nations – Kenya, Albania and Lebanon.
- Approval of the budget of the Association, which, for 2018, totalled an annual income of more than €900,000 with an expenditure of about €850,000 to create a surplus of about €50,000.
- Approval of the proposal from Norway to commission an external audit of the organization, operation and governance of the Association as a one-off investment into its strategy for the future.
- Publication and release of the new Emerald Book form of contract prepared specifically for underground construction contracts by the ITA in collaboration with FIDIC.
- Approval of the proposal by Iran to establish a new Working Group on the Design and Construction of Shafts.
- Approval and publication of reports and developments by other Working Groups and by the three Committees of the Association – ITACUS, ITACOSUF and ITAtech.

New publications include from Working Group 2 new guidelines for the design of segmental tunnel linings; from Working Group 5 a client's guide for high pressure compressed air work; and from Working Groups 14 and 15 a joint report on handling, treatment and disposal of excavation materials.

The ITAtech Committee produced new reports on a practical approach for controlling blasting vibration and optimising advance in tunnelling, and a second updated guideline on the rebuild of machinery for mechanised tunnel excavation.

The ITACOSUF Committee on safety in underground spaces, published a report on the current practice for design of cross-passages to support safety in rail and metro tunnels.

WTC experiences

As is the annual tradition at WTCs, there were reasons to complain, and so for Naples it was the unseasonal rain and cold temperatures that ruined high expectations of glorious Mediterranean sunshine as well as a surprising shortage of baristas to serve impatient queues with Italian espresso; a spread out venue of conference rooms and exhibition areas that was demanding even of the fittest; and a wifi service, gratefully sponsored by SWS Engineering, that proved unable in its capacity to host all the users as well as the app designed to help delegates navigate the technical sessions, poster sessions, meetings, and indoor, outdoor and marquee exhibition areas.

Nonetheless, SIG, the Italian Tunnelling Society and its organising committees, staged a WTC with a well constructed and packed programme of technical paper presentations and special social events.

At the Opening Ceremony, relayed by video link between two theatres to accommodate the near 2,000 attendees, Martin Herrenknecht delivered the Sir Alan Muir Wood Lecture, taking the audience on a journey of TBM development through his own personal career as a mechanical engineer and as founder of Herrenkencht AG. This ranged from his first underground job working on the open-face Big John machine of the early 1970s in Switzerland, through the development of machines to cope with increasingly demanding geological and logistical challenges. Most recently, developments include sophisticated electronic systems and technologies that increase the safety and performance of TBMs and contribute to reduced excavation costs.

In an engaging keynote presentation, Pietro Salini, CEO of Salini Impregilo, emphasised the need to attract young professionals to the industry and addressed the topic of risk aversion and unrealistic competition in the contracting sector, saying that the continuing attempts by owners to shift risk onto the contractors, that are bidding with ever decreasing margins, will lead to "extinction" of contractors.

The WTC in Naples also hosted more than 170 exhibitors representing all sectors of the industry and from all corners of the world.

All in all a busy, productive, significant and progressive event. ■

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Video reporting

Through 2019, *TunnelTalk* reported from around the world, providing coverage of major conferences and projects, as well as interviewing key industry players.

View the *TunnelTalk* video reporting on the *TunnelTalk* YouTube channel:

www.youtube.com/user/*TunnelTalk*Videos/videos

TunnelTalk *reporting of the WTC event (above) and Salini keynote address (below)*

Jenny Yan of China takes the reins of the ITA

Roland Herr for *TunnelTalk*

In being elected President of the International Tunnelling and Underground Association for the period 2019-2022, Professor Jenny Jinxiu Yan said: "It is an honour to be the new ITA President. I understand that it means responsibilities, commitments and dedication. To meet the new challenges, it is important to make a joint effort to find new solutions to contribute to the sustainable development goals of the United Nations by 2030. To achieve this we must first, enhance communication with related international organisations, national policy-making forums, and well-known international banks to increase the contributions of tunnelling to the implementation of sustainable development. Secondly, to improve communication and exchanges between Member Nations and the industry by encouraging experience sharing through organising symposiums, training courses and other similar events. Thirdly, recognise the achievements of our industry and promote knowledge sharing and the application of well-recognised new technologies among all parties involved, including decision makers and investors. Finally to focus on the common concerns and challenges of our industry and endeavour to seek new solutions through collective efforts by all ITA members and industry."

Jenny Jinxiu Yan has been engaged in the industry for more than 30 years

Yan has been involved in the tunnelling industry for more than 30 years and is Deputy General Manager of the China Railway Academy Company. As the team leader for research, consulting and design, she has been involved in the most challenging railway, highway, metro and water tunnel projects in China as well as internationally in Malaysia, Laos, Nepal and Morocco and many other countries, especially for the early project stages.

In the last 40 years, China has completed an extraordinary amount of tunnelling activity. By the end of 2017, China had built and put into service 127,000km of railway, including 25,000km of high-speed connections, with 14,700 tunnels on the lines adding to a total of 15,781km. Of 4.77 million kilometres of highways built, there are more than 16,000 tunnels totalling 15,240km.

Transit growth in China continues and has accelerated in recent years. By the end of 2017, there were 165 rail-transit lines in 34 cities totalling 5,033km with 3,884km underground. "Rapid transit is ideal for the big cities of China and is unchallenged in its ability to transport large numbers of people at high frequency and quickly over short distances," said Yan.

"The progress of tunnelling in China would not have been possible without the knowledge and experience sharing and the strong support from the international tunnelling industry," added Yan. "All the involvement and contributions are important for progress and it is very much appreciated by the Chinese industry. Meanwhile, the experiences and lessons learned by the Chinese over the past 40 years are very costly and of value to countries planning similar projects. In return, we are ready to share these experiences internationally, through conferences, symposia, workshops and other media, as we have in the past. The challenges include not only the size of the tunnels, but include also the logistics and demands of super long, very deep tunnels with large cross sections and at high altitude, as well as tunnelling in very complex conditions, such as active faults, extreme sequencing ground, permafrost, high geothermal ground and remote locations. China will need help and involvement from the international industry to overcome these challenges together."

"My first involvement in the ITA was in 1990, during the 16th ITA General Assembly in Chengdu, China. I deeply understand the extreme importance for international exchanges and cooperation, in which ITA plays a key role. I have been a link between the Chinese tunnelling industry and the ITA for many years." ■

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Risk reduction for underground works

FIDIC News Release

Emerald Book contract specifically for underground projects

To address the uncertainty and contractual risks associated with tunnelling and underground works, FIDIC, the International Federation of Consulting Engineers, and ITA, the International Tunnelling and Underground Space Association, published the new form of contract of underground works. The Emerald Book takes into account construction practicability, time and cost, and the geological, hydrogeological and geotechnical properties of the ground which determine the methods required for successful implementation of underground projects.

Launch of the Emerald Book in 2019 follows several years of intensive work by a joint task group of representatives from FIDIC and ITA who identified several issues that the contract should address to promote equitable risk allocation and the effective dealing with conditions typically unforeseeable in such projects.

The following are specifically addressed in the new contract:

- Allocation of risk.
- Disclosure of all available geological and geotechnical information.
- Inclusion of a contractual geotechnical baseline.
- Inclusion of a tailored Unforeseeable Physical Conditions clause.
- Implementation of a ground classification system and of supporting particular conditions that properly reflect the effort of excavation and stabilisation.
- Time for completion to be largely influenced by ground conditions.
- Provision of a flexible mechanism for remuneration according to ground conditions, foreseen and unforeseen.
- Guidelines to help anticipate risks associated with works.

With the increasing need for underground works, take-up of the new Emerald Book contract is expected to be widespread.

"Working together, FIDIC and ITA have created a contract that we believe will command the respect and authority of the tunnel engineering and construction sector that both clients and contractors can use with confidence. The new Emerald Book addresses several critical areas that should lead to the smoother running of contracts in the growing tunnelling and underground works sector," said Zoltán Záhonyi, FIDIC Contracts Committee Chair.

"The Emerald Book will bridge an important gap. Despite all the technological developments of equipment and techniques in the field, many underground construction projects end up unsuccessful because of contractual disputes," said Tarcisio Celestino, President of the International Tunnelling and Underground Space Association. "The Book brings together the result of the expertise and respectability of ITA-AITES and FIDIC in the fields of contracts and specifications for underground construction."

The new contract is available for purchase from the FIDIC online bookshop. ■

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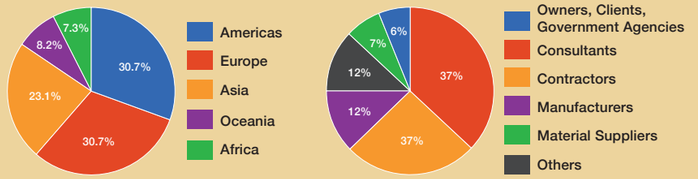
TunnelTalk *Direct by Design*

At the start of the 2020 decade, *TunnelTalk* celebrates more than 10 years in publication and its 10th edition of the Annual Review yearbook magazine.

Through the years, the magazine has grown exponentially. It now has an online Archive of more than 3,500 articles and videos and a readership of between 80,000 and 120,000 reader sessions per month. Since launch of the magazine in 2008, more than 7,500 professionals have signed up to receive the free weekly news Alert email distributed every Thursday.

The value of the editorial coverage and of the magazine readership has attracted dedicated long-term readers, advertisers and media partners. For our advertisers, our readers are your customers. For our readers, our coverage is your link with the industry. ■

TunnelTalk readership by region (left) and Alert recipients by profession (right)



The printed Annual Review yearbook looks back at the year just past and encapsulates a synopsis of the leading events, projects, company developments and honours. The Annual Review is published as a simulated digital edition, and printed in hard copy for distribution at industry gatherings and conferences. All editions of the Annual Review are available for purchase in both digital and hard copy format. ■

Progressing into a second decade

Ten years has passed so quickly. From its launch in 2008 at the World Tunnel Congress in Agra, India, *TunnelTalk* has reported on the projects, developments and events that have shaped the industry through the decade. Its reporting has:

- Followed the progress of extraordinary projects from conceptual design to contract bidding and award, through construction and on to completion and opening for service;
- Kept abreast of news and developments that have marked the life of the industry through company mergers, buyouts, career moves and financial fortunes;
- Tracked the design, manufacture and application of important project TBMs and other equipment and technical developments;
- Reported on the major conferences, congresses, exhibitions and events that keep the international industry connected and advancing, both technologically and socially;
- Provided the lead in many instances to bring developments in the world of underground space to a wider audience including the general public and other professions that would be otherwise oblivious to the remarkable infrastructure being developed under our cities, seas and across nations.

The following pages celebrate the highlights that have marked the progress of the industry through the last decade of *TunnelTalk* reporting with more detail to be found in the reports on the web magazine and through its free-to-access Archive.

The Archive library is one of our most valued services. Through its efficient search facility, a full list of reference results will take readers and researchers to the information they are looking for. A search of the web brings up

TunnelTalk references for anyone researching underground development and its history.

As well as article reports, *TunnelTalk* was the first to bring video reporting to the readers. Our videographers and editors have reported on many of the major projects through the years, have covered the main annual conferences and events, and have produced face to face interviews with industry leaders. The video reports are listed in our Archive and on the *TunnelTalk* YouTube channel.

The publishing industry has been transformed through the past decade, with the advance of the digital age. *TunnelTalk* began as a web publication, lifting the content of a printed magazine, in all its facets, off the page and onto the screen, leaving behind the time delay and space limitation disadvantages of printed magazines and embracing the immediacy and global accessibility of the web.

Publication of the magazine and its Annual Review yearbook is the collaboration of a team of dedicated professionals. From its launch in 2008, the magazine is a credit to the efforts of the engaged team of self-employed freelancers and contractors. The current team, many with long-term service, includes: freelance journalists Jonathan Rowland, Patrick Reynolds, Karen Martin, Armand van Wijck, Eugene Gerden, Jaroslaw Adamowski, Roland Herr; technical subeditors Julie Burchell, Laura Skorczeski; head of advertisement sales Adela Buglass; video producer and editor Mark Charles; web magazine production and developers Avneesh Jain and his CodeHall team in Bangalore, India, including Suman and Santhosh, and graphic designer for the magazine and production editor of the Annual Review yearbook since its first edition in 2010, Claire Hunt.

Others who have been instrumental in the success of *TunnelTalk* through the years have included original designer of the web magazine in 2008 Akhtar Hussain; early web magazine production team Absolute Infotech; Peter Kenyon, editor and journalist from 2010 to 2016; advertisement sales managers from 2010 to 2019 Christie O'Reilly and Binda Punj; accounts manager 2010-2019 Katerina Chvojka, and continuing business advisers and consultants Katrina Santa Maria, Louise and Josephine Wallis and journalist, collaborator and video editor from launch in 2008, Paula Connor.

At the end of a thrilling first 10 years and at the start of the second, we thank all our readers and our media partner advertisers for their appreciation of our work and for their ongoing readership that will enable us to continue our editorial coverage and grow the business in the years to come. ■

- Shani Wallis, Publisher and Executive Editor

From left: On site reporting; bauma India; Agra WTC 2008; Media partner at many congresses, with an exhibition booth; bauma China

TUNNELTALK ANNUAL REVIEW 10TH ANNIVERSARY ISSUE

Europe

Connectivity beneath mountains, under the sea, between countries and across cities was the focus in Europe for the past decade. TBMs, immersed tubes, drill+blast and open-face excavations were supported with every tool possible to achieve success. *TunnelTalk* has followed leading projects through their journeys.

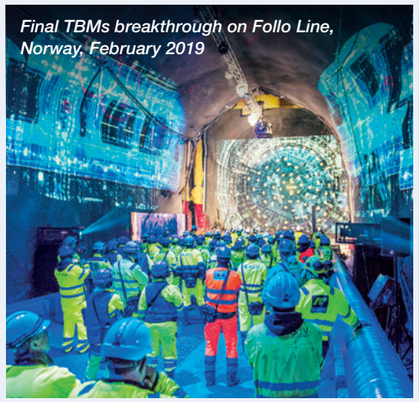

Final TBM breakthrough, Gotthard baseline railway, Switzerland, March 2011

Rail connections

Leading the way for European connectivity, and after 17 years in construction, was the Gotthard baseline rail link, completing all headings for the first of the twin tubes in 2010, for the second in 2011 and opening to traffic in 2016. This was followed by the Brenner baseline project with start of its exploratory bore in 2010 and all main line excavations currently progressing. Other main rail connection projects during the decade have been Hallandsås; Stuttgart 21; Mont Cenis on the Lyon-Turin baseline, the hard rock TBM and segmentally lined Follo Line, Norway; Koralm and Semmering rail lines in Austria; Crossrail and the HS2 high speed rail link in the UK; and the mega immersed tube Marmaray link under the Bosphorus; the combined road and rail Fehmarnbelt link; and plans for the rail link between Helsinki and Tallin. ■


Brenner Baseline begins, Austria-Italy, 2010


Fehmarnbelt Denmark-Germany sea link approved in Denmark, 2014


Final TBMs breakthrough on Follo Line, Norway, February 2019


Crossrail excavation finalised, UK, June 2015


Ground freezing assists Hallandsås railway excavation to breakthrough, Sweden, June 2010

Road connections

Highway links of distinction have provided undersea connections in Turkey and Norway with the Eurasia double deck TBM project under the Bosphorus in Istanbul and the drill+blast headings deep beneath the seabed for the Ryfast and Rogfast links in Norway. Highway links also included the twin tube TBM drives for the Sparvo project and the Sicily Caltanissetta project in Italy and three planned projects in the UK to bypass the Stonehenge monument and two highway links under the River Thames, the Silvertown project in London and the Lower Thames crossing to the east of the city. ■


Eurasia highway under the Bosphorus in Istanbul, Turkey, 2015


Sparvo twin-tube highway, Italy, 2013


Drill+blast under the sea for Ryfast link, Norway, 2016


Grand Paris Express, France, 2017


Cityringen, Denmark, 2010

Metros

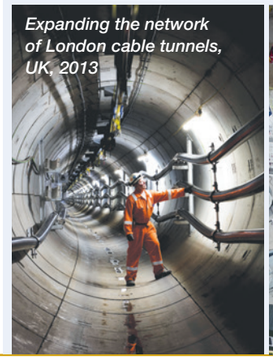
Extension and expansion of the metro systems in most major cities of Europe have progressed through the past ten years, none more ambitious and extensive than the Grand Paris Express programme in France. New lines and extensions have been added also to the metro systems in London, Milan, Berlin, Stockholm, Amsterdam and the new Cityringen line in Copenhagen. ■


Amsterdam Metro, the Netherlands, 2010

Additional infrastructure projects

Significant underground projects planned and progressed across the years have included projects in the UK for the Woodsmith potash mine, the cooling water systems for the new Hinkley Point nuclear power plant, the Thames Tideway CSO interceptor project in London, and extension of the network of high voltage electricity cables under the city of London including in preparation for the London Summer Olympic Games in 2012. ■


Tideway Lee Tunnel as the start of the Tideway CSO in London, UK, 2011


Expanding the network of London cable tunnels, UK, 2013


Woodsmith potash mine shaft sinking operations, UK, 2018


TBMs forged the mighty wastewater Emisor Oriente project, Mexico, 2009


Mega TBM excavation of the SR99 double deck Alaskan Way higway in Seattle, USA, 2009

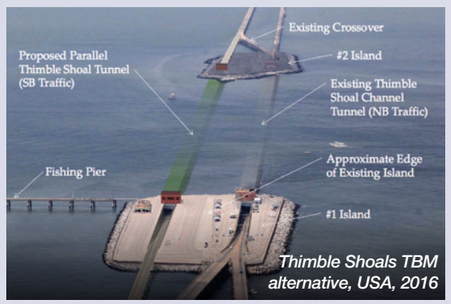

Largest ever hard rock TBM excavated the Niagara hydro waterway, Canada, 2009

North America

Over the past 10 years, Canada, the USA and Mexico have advanced a rich heritage of cutting edge underground development employing the largest ever hard rock TBM for the Niagara hydro power water diversion tunnel in Canada, the largest ever EPBM for the Alaskan Way SR99 viaduct replacement highway tunnel in Seattle, USA and one of the longest wastewater projects advanced as a single project for the 62km long Emisor Oriente in Mexico City. For railways, roads, metros, CSO interceptors and potable water systems, North America has taken the industry and its technology to extremes.

Road connections

Along with the mega TBM drive for the SR99 highway tunnel in Seattle, road connections in the USA have included the TBM drives for the Port of Miami connection in Florida, the Midtown immersed tube link under the Elizabeth River in Virginia, and the TBM alternatives to immersed tube projects to double the capacity of the Thimble-Shoals and Hampton Roads crossings of Chesapeake Bay. ■



Thimble Shoals TBM alternative, USA, 2016


Midtown immersed tube crossing of Chesapeake Bay, USA, 2011


First use of SEM in Los Angeles for Metro Regional Connector, USA, 2014


Mined alternatives to open-cut for the Ottawa Metro, Canada, 2012

Metros

While Phoenix in Arizona rejected the underground for the start of its LRT system, underground works extended the networks in most cities of North America during the decade, most ambitiously in Los Angeles, New York City, San Francisco, Seattle, Toronto, Ottawa, and Mexico City. The long-promised extension of BART to San Jose is now likely to build the first single-tube, double-track metro line and with BART also preparing for a second metro crossing of San Francisco Bay. ■


TBMs connected open-cut stations for the Seattle Metro, USA, 2010

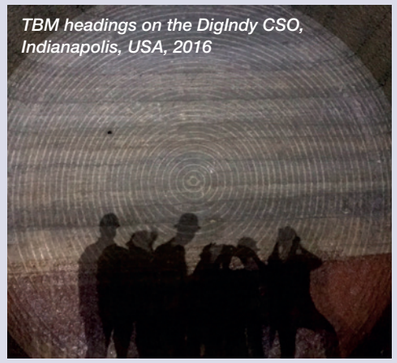

Operating pressures of more than 8.9 bar on Lake Mead, Nevada, USA, 2009

Water supply

Supply and management of potable water in the USA presented the industry with its most challenging projects to claw success from the extremes on the Arrowhead tunnels in the hills behind Los Angeles; on the Seymore Capilano project in Vancouver; at Brightwater in Seattle; the first TBM bored tunnel under San Francisco Bay; the daring Lake Mead intake in Nevada; and most recently for the Delaware aqueduct repair bypass in New York State. The same high bar of challenge will continue into the long distance TBM excavations required for the WaterFix project in California. ■


Success from extremes at Arrowhead, California, USA, 2009

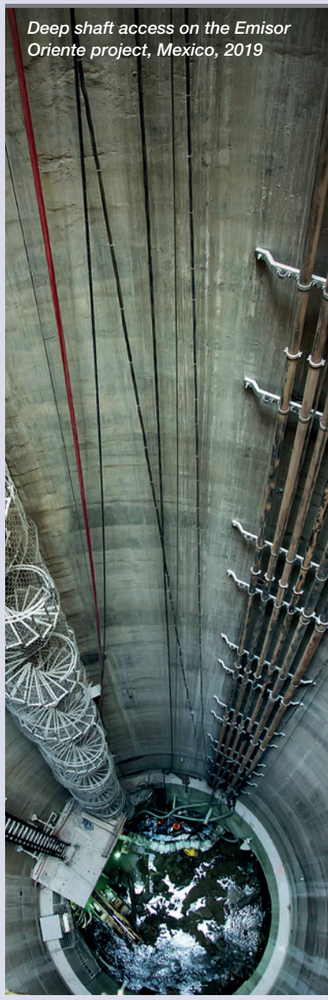

Twin TBM drives at Seymour Capilano, British Colombia, Canada, 2010


TBM headings on the DigIndy CSO, Indianapolis, USA, 2016

Sewers

It has been the interception of CSOs to meet clean water regulations and manage wastewater that has continued to demand extensive tunnel networks in many cities across North America including Indianapolis, Columbus, Cleveland, Washington DC, Detroit, St Louis, and Dalles in the USA; Toronto in Canada and the capital city in Mexico. Design of a post tensioned segmental lining is the particular feature on the new Los Angeles sewer conveyance tunnel now in its early stages of construction. ■

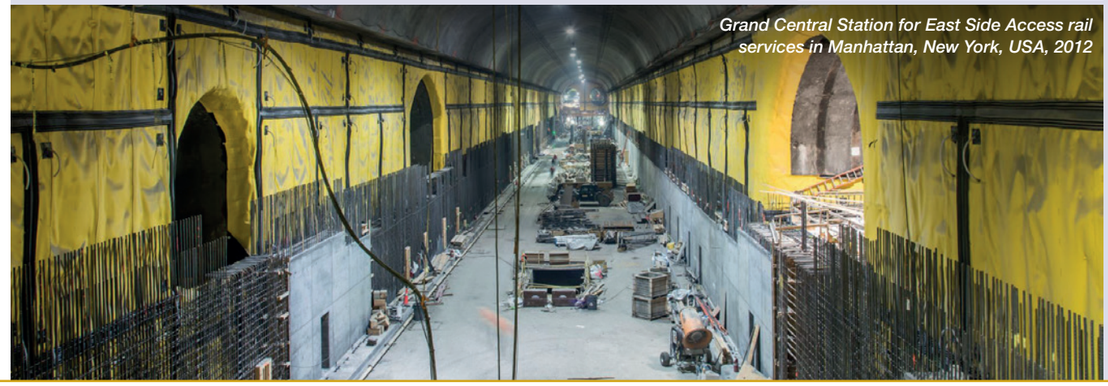

One TBM, two cutterhead diameters for Mill Creek CSO, USA, 2019


Deep shaft access on the Emisor Oriente project, Mexico, 2019

Rail connections

Rail projects have a checkered history in recent times in North America, and while Virgin Hyperloop One is studying possible high speed links, California is progressing the first dedicated high speed rail route between Los Angeles and San Diego in the south, to San Francisco and Sacramento in the north. After termination of the Access to the Regions Core (ARC) project in 2010, and while increased capacity under the Hudson between New Jersey and Pen Station in Manhattan is in design under the new Gateway project, the elements of the East Side Access project to bring Long Island Railroad services into the most spectacular underground terminus cavern under Grand Central Station has grabbed the headlines through the decade. ■


California creates the start of dedicated high speed rail in USA, 2012


Grand Central Station for East Side Access rail services in Manhattan, New York, USA, 2012

Awards, honours and tributes

Outstanding achievements, that can often go unheralded, come to the attention of the international industry through its series of different awards. Chief among these on the global scale are the ITA Annual Awards which were launched in 2015. As well as highlighting projects and innovations of distinction, the Lifetime Achievement Award recognises the careers of individuals dedicated to the advancement of industry. National awards add to the honour of peer recognition, including the annual TAC Awards in Canada, the UCA and Beavers Awards in the USA and the BTS James Clark Medal in the UK. ■

ITA Presidents

2019-	Jenny Jinxiu Yan, China
2016-2019	Tarcisio Celestino, Brazil
2013-2016	Søren Eskesen, Denmark
2010-2013	In Mo Lee, Korea,
2007-2010	Martin Knights, UK

ITA Lifetime Achievement Awards

2019	Dr Harvey Parker, USA
2018	Dr Evert Hoek, Canada
2017	Einar Broch, Norway
2016	Dr Martin Herrenknecht, Germany
2015	Professor Sebasiano Pelizza, Italy

John Bartlett of the UK, honoured in 2018 with the Sir Frank Whittle Medal of the Royal Academy of Engineering for his development of the slurry TBM concept

Dick Robbins receives the Benjamin Franklin Institute Medal in Engineering 2009

Industry news and events

Along with the many projects that progress through the years, there has been the process of doing business with company mergers, acquisitions, buyouts and restructures changing the face of the industry and marking its evolution and history. The thread keeping everyone in the industry up-to-date with developments is the vibrant calendar of industry events that have been fixtures in the business year for delegates and exhibitors until the coronavirus pandemic of early 2020 which caused cancellation of gatherings in person and moved many to virtual online alternatives.

Lessons learned

For all the many, many successes that are both reported and go unrecognised, there have been a set of significant failures in the industry in the decade, none more awful than the collapse of an open cut excavation on the Cologne Metro in Germany; none more deadly than the collapse of the undersea gas pipeline heading in Japan; none more disruptive than the TBM rail heading failure under the mainline surface rail tracks in Rastatt, Germany; while in the hydro industry, collapses of waterways after the start of operations have proven costly to the operator and the insurance industry. These and other collapse events are the hazards of underground construction that risk registers, introduced by the construction and insurance industries, work hard to mitigate, and are events from which practitioners in the industry must continue to learn. ■

Collapse of the TBM rail link under the mainline railway at Rastatt, Germany, 2017

Devastating collapse of an open cut crossover and sump structure in Cologne in 2009

Many a sinkhole has provided a hard lesson for competent excavation

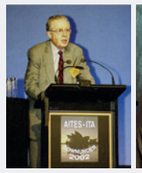
Failure of an undersea TBM heading in Japan that cost the lives of five workers, 2012

Failure of the operating headrace on the Gilgel Gibe II hydro scheme in Ethiopia, 2010

Headrace collapse after commissioning of the Glendoe scheme in Scotland, 2009

In the decade, several industry statesmen were remembered

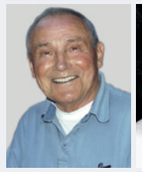
See p95 for additional tributes



Sir Alan Muir Wood 1921-2009

Franz Pacher 1919-2018

Dr Zdenek Dan Eisenstein 1936-2009



Siegmund Babendererde 1927-2012

Thomas R Kuesel 1926-2010

Walter Grantz 1929-2018

Don Deere 1922-2018

Zdzislaw Richard Bieniawski 1936-2017

James McKelvey 1954-2015

Terry Hulme 1929-2017

Dr Ralph B Peck 1912-2008

Tor Brekke 1934-2009

Dick Robbins 1933-2019

James Monsees 1937-2019

Enrique Fernández González 1958-2019

Mergers and buyouts

TunnelTalk has kept track of the changing face of the industry in:

TBM manufacturing:

2008 Lovat sells to Caterpillar, 2014 Caterpillar sells Lovat to LNSS, China
2013 China Railway Tunnelling Equipment buys Wirth from Aker Solutions, Norway
2015 JIMT TBM manufacturing combines JFE, IHI and Mitsubishi Japanese and buys 50% of Terratec in 2018
2015 Mühlhäuser acquires Obermann and takes over TBM manufacturer NFM in 2018 from troubled Chinese owner NHI since 2007
2020 Mühlhaüser liquidation sees assets bought by Mining Equipment and Bauer MAT and NFM Engineering established by BMS, France

Equipment and materials suppliers:

2008 Zoomlion, China acquires Italy formwork specialist CIFA
2010 Normet and TAM form global partnership
2012 BASF sells Meyco division to Atlas Copco
2012 Sany, China buys Putzmeister
2012 Normet aquires D-Bolt product line
2014 Bekaert+Maccaferri combination and absorbs Maccaferri in 2020
2020 Keller mergers North America subsidiaries under Keller brand
2020 BASF sells Construction Chemicals to Lone Star Funds

The consulting engineering world:

2009 Balfour Beatty buys Parson Brinckerhoff and sells to WSP in 2014
2010 URS Acquires Scott Wilson; AECOM acquires URS in 2014
2010 Jacobs acquires Jordan, Jones and Goulding
2011 CH2M Hill buys Halcrow
2013 COWI acquires Jenny Engineering, USA
2014 Donaldson Associates, UK acquired by COWI
2014 Parsons aquires Delcan, Canada
2014 Jacobs Associates merges with McMillen
2015 Hatch and Mott MacDonald split their North America JV
2017 Jacobs acquires CH2M
2017 SNC-Lavalin of Canada takes over Atkins
2018 COWI acquisition of ILF USA assets

Construction:

2011 Tutor Perini buys Frontier Kemper
2013 Salini Construttori and Impregilo join forces
2014 Bilfinger withdraws from civil tunnelling, division acquired by Implenia
2014 Hochtief seizes control of Leighton, Australia
2014 Hochtief sells John Holland, Australia to CCCC, China
2015 Bilfinger civil tunnelling division is acquired by Implenia
2015 Breakup of Seli SpA, Italy
2017 CCCI, China acquires Aecon, Canada

Events

ITA General Assemblies and World Tunnel Congresses

WTC 2008	Agra, India
WTC 2009	Budapest, Hungary
WTC 2010	Vancouver, Canada
WTC 2011	Helsinki, Finland
WTC 2012	Bangkok, Thailand
WTC 2013	Geneva, Switzerland
WTC 2014	Iguassu Falls, Brazil
WTC 2015	Dubrovnik, Croatia
WTC 2016	San Francisco, USA
WTC 2017	Bergen, Norway
WTC 2018	Dubai, UAE
WTC 2019	Naples, Italy

National Events

USA – RETC and NAT

2008	NAT San Francisco
2009	RETC Las Vegas
2010	NAT Portland, Oregon
2011	RETC San Francisco
2012	NAT Indianapolis
2013	RETC Washington DC
2014	NAT Los Angeles
2015	RETC New Orleans
2016	NAT with WTC San Francisco
2017	RETC San Diego
2018	NAT Washington DC
2019	RETC Chicago

STUVA, Germany

2011 Berlin, 2013 Stuttgart, 2015 Dortmund, 2017 Stuttgart, 2019 Frankfurt

AFTES, France

2014 Lyon, 2017 and 2018 Paris

Salzburg Geocolloquium

Every year in October, Austria

bauma equipment trade shows

2010, 2013, 2016, 2019: Munich, Germany
2016, 2018: Shanghai, China
2011, 2016, 2018: Mumbai/New Delhi, India

Jenny Jinxiu Yan, first woman President of the ITA

Careers in underground engineering

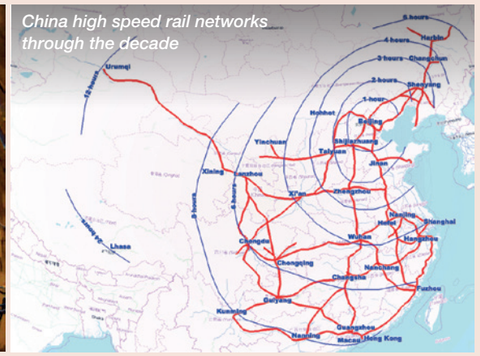
It has been a decade that has seen women breakthrough a barrier to become vital members of underground engineering and construction teams. Rising to high managerial positions, as well as being onsite and in the thick of things, has presented women with career paths in the rewarding world of underground engineering.

This is assisted by the different degree and training courses now offered in tunnelling and underground space development, by universities and polytechnics, as well as a packed programme of topic specific short courses for new recruits to the industry. There are also many industry apprenticeship schemes and hands-on training academies that are actively ensuring a new generation of industry professionals. Young Member groups of the ITA and national tunnelling societies provide the networking opportunities among like-minded young professionals. ■

Ladies celebrating their roles on tunnelling projects

It is a changing face in the world of underground engineering


Yulhyeon Tunnel high speed railway, Korea, 2015



Rail connections

It has been the expanse of high-speed rail in China that has dominated the decade with thousands of kilometres of rail being laid with a high percentage below ground. Korea also has an ambitious rail programme to connect people to any point in South Korea from any other point in the country in less than half a day with the 50.3km long Yulhyeon Tunnel assisting on the Suseo to Seoul Link. The Hong Kong Express rail link with China precedes further plans by China for international links including a rail link across the Himalayas to India and across to Europe to create a new Silk Road as part of its One Road, One Belt aspirations. ■

Asia

Longer, deeper, faster, continuous and more controlled have been the features of the industry in Asia through the past decade. Continuous expansion of metro systems in Singapore, Delhi, Kuala Lumpur, Tokyo, Seoul, Bangkok, Beijing and other cities in China engage experienced teams without long, disruptive periods of suspension in planning, financing and implementation. China has achieved a network of high speed rail and highway connections across the country with astonishing speed, and at the beginning of the 2020s, is bringing its expertise to other countries of the world. Hydro development, particularly in the Himalayas, together with long distance water supply lines and expansion of urban potable water and wastewater systems, round off what is undoubtedly the most active underground infrastructure region of the world. The two devastating earthquakes and tsunamis that hit the Pacific region in 2004 and Japan in 2011 were a powerful impetus to the industry to assist in the global search for resilient cities and societies with underground infrastructure playing a vital role in the overall strategies.


Mega TBMs for Tokyo Ring Road, Japan, 2017


Tuen Mun-Chek Lap Kok undersea highway, Hong Kong, 2014


Final element in Hong Kong-Zhuhai-Macao immersed tube sea link, 2018

Road connections

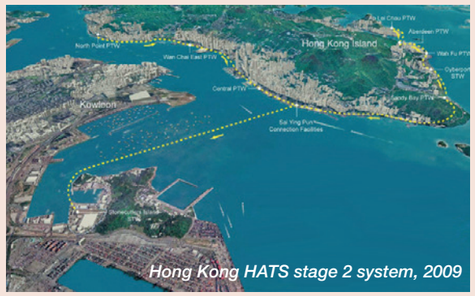
The Hong Kong-Zhuhai-Macao link and the Tuen Mun-Chek Lap Kok subsea highway link in Hong Kong where technological feats in immersed tube construction and TBM bored excavation, each introducing new approaches to achieving the goal. In Japan, mega TBMs are busy excavating the underground alternative to surface and elevated highways to complete ring roads around Tokyo, in preparation for the 2020 Summer Olympics which have had to be postponed to Summer 2021 due to the 2020 coronavirus pandemic. ■


Record TBM advance rates were achieved on the Bheri Babai project, Nepal, 2019


Kishanganga hydro success, Kashmir, India, 2012

Hydro and water

Despite the legendary troubles on excavations in the Himalayas, there have been significant successes during the decade. The TBM operation for the Kishanganga hydro scheme in Kashmir and for the Bheri Babai water diversion project in Nepal provide positive prospects for TBM operations for the many hydro projects planned for the countries of the formidable mountains. Hydro schemes and long water conveyance projects have also advanced in Laos, Vietnam, Thailand, Malaysia and India, with Singapore and Hong Kong advancing their respective DTSS and HATS wastewater systems employing both TBMs and drill+blast with pre-excavation grouting to overcome geological extremes. ■



Hong Kong HATS stage 2 system, 2009


DTSS Phase 1 with interior protective membrane and invert yet to cast, Singapore, 2010

Metros

No more elevated metros (to prevent trapping heat and air pollution in the cities) or on the surface (to preserve valuable land space) are policies being followed by many mega cities in Asia. Many also have no other option than to go underground in dense and historic urban areas. Singapore leads with a non-stop metro construction programme, followed by India, with the start of new underground metro systems in Bangalore, Mumbai, Chennai, Lucknow, Pune and Jaipur, adding to expansion of the first metro system in the country in Kolkata and the rapid expansion of the network in Delhi. Kuala Lumpur, Malaysia, continued expansion of its underground metro following success with the TBM-bored SMART stormwater and road tunnel in the early 2000s. ■

Many a celebration for metro breakthroughs in India and across Asia


KVMRT, Kaula Lumpur, Line 1 now in operation and Line 2 in excavation

Australia and New Zealand

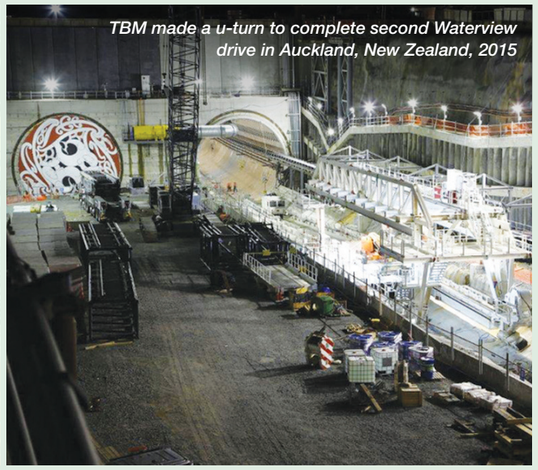
Per head of population and as a percentage of gross domestic product, New Zealand and Australia have invested more in underground infrastructure during the decade than most other countries. Road, rail, metro, water and hydro schemes have called on the application of mega TBMs, heart of the city excavations, successes and record speeds of advance by fleets of equipment and teams of skilled engineers and workers with plans to keep the advancement of underground infrastructure going and going for the coming decades.


Twin tube TBM road connections, Brisbane, Australia, 2013

Highway connections

Large diameter TBMs and impressive roadheader and drill+blast excavations have created long networks of underground highways in all major cities, with two mega TBMs ready to start excavation of the West Gate highway in Melbourne, following the mega TBM that completed the Waterview highway in Auckland; speedy TBMs for the Clem 7, Airport Link and Legacy Way highways in Brisbane, and fleets of 20 and more roadheaders working through Hawkesbury Sandstone for the Northconnex and Westconnex freeways in Sydney. Perth had its Polly Farmer top-down bypass built in the late 1990s and Adelaide opened its Crafers twin tube highway in 2000. ■


Two TBMs of 15.6m diameter for West Gate project, Melbourne, Australia, 2019

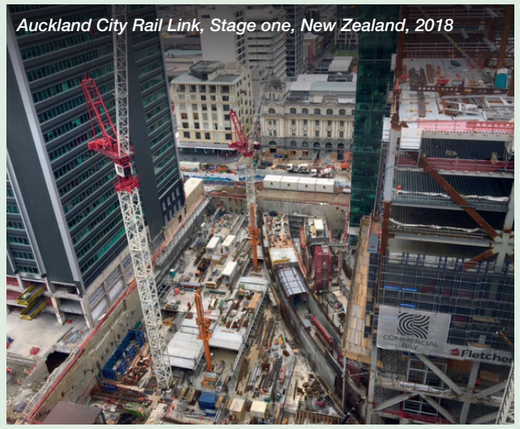

TBM made a u-turn to complete second Waterview drive in Auckland, New Zealand, 2015


Fleets of roadheaders create the NorthConnex and WestConnex highways in Sydney, Australia

Rail and metro

Sydney, Melbourne, Auckland, Brisbane and Perth are leading the way with extensions and new underground lines for their metro and rail networks. Sydney has achieved remarkable advance rates for the North West Rail Link and this continues for the Metro City and Southwest extension with its slurry TBM pass under Sydney Harbour. While the sandy soils of Perth caused problems on the Forrestfield extension to the new airport terminal, all TBM and cross passage excavation was completed in early 2020. The Cross River rail link mobilised in Brisbane in early 2020 and the first TBM breakthrough for the Melbourne Metro was celebrated in February 2020. For Auckland, construction and excavation of the City Rail Link is being threaded through and beneath the city centre to transform rail travel for the city. ■


Smart metro work in Melbourne, Australia, 2019


Auckland City Rail Link, Stage one, New Zealand, 2018


First TBM launched for Forrestfield airport link, Perth, Australia, 2017

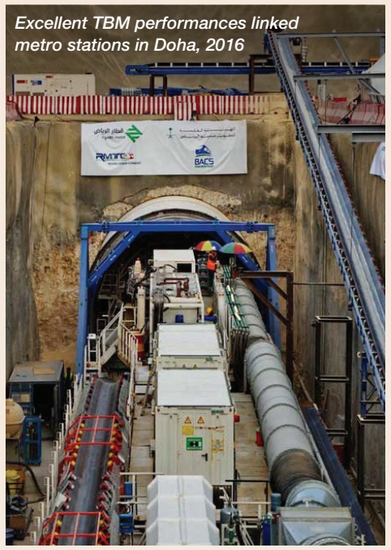

Early works for the Auckland interceptor, New Zealand, 2019

Hydro and water

With major sewer and outfall works completed in previous decades for Sydney, Melbourne and Auckland, it is the new interceptor project in Auckland that is the focus for the coming years in the water industry with work just beginning on the 14.7km long drive. For the hydro industry, the Snowy 2.0 pumped storage project in New South Wales will complete the final element of the brave and ambitious Snowy Mountains project of the mid-1900s with the Kidston project in Queensland nearing approval for construction. ■

Snowy 2.0 prepares for arrival of three TBMs for headrace, tailrace and access excavations, Australia, 2020


High quality finish for STEP wastewater network, Abu Dhabi, UAE, 2012


Excellent TBM performances linked metro stations in Doha, 2016

Middle East

Metros and wastewater systems have created the interest for the industry in the iconic modern highrise cities of the Middle East. Most impressively has been construction of the Doha Metro in Qatar where, in 26 months, 21 TBMs completed 56km of twin-tube metro running tunnels across four metro lines and by four contracted JVs. Similar concentrations of running tunnels and station excavations have been achieved for the Riyadh Metro in Saudi Arabia, while in Dubai, plans to host Expo 2020 initiated extension of its Metro Red Line to the new airport and exhibition grounds and construction of a deep stormwater drainage project with a network of sewer connections to direct wastewater to a new treatment works. In Abu Dhabi, it was the extensive urban drainage STEP, Strategic Tunnel Enhancement Programme, comprising 41km of main trunk lines and 51km of sewer links that provided an industry focus. ■

Middle East, Africa, South America

For many countries of Africa, the Middle East and South America, the underground excavation industry is young or yet to take a place in national development. While there are pockets of activity, and very impressive projects, in Doha, Dubai, Saudi Arabia, South Africa, Lesotho, Egypt, Chile, Brazil and Argentina, and the start and advance of activity in Nigeria, Kenya, Peru, and Ecuador, the need for underground infrastructure for wastewater management to hydro power generation and all in between is great, and is awaiting the investment and attention to procurement to materialise.


Water will flow from a new dam and reservoir on the Senqu River to the Katse reservoir in Lesotho, 2018

Africa

Reporting from Africa for the decade has centred mainly on activity in South Africa and Lesotho, Egypt and Algeria. For South Africa and Lesotho, the news is for procurement of Phase II of the binational Lesotho Highlands Water Project with a 38km x 5m diameter gravity water transfer from the new Polihali Dam reservoir to the existing Phase I Katse Dam reservoir. In Egypt and Algeria, it has been news of metro extensions in Cairo and Algiers with two new TBM road tunnels under the Suez Canal in Egypt. ■


Ground freezing assisted excavation of cross passages under the Suez Canal, Egypt, 2019


Several metro and rail lines were developed during the decade

South America

Hydro schemes and metros have been the focus in South America with baseline rail and road links through the Andes being the ambition. In Brazil, extended metro and road services were a focus in Rio de Janeiro in preparation for hosting the 2016 Summer Olympics Games, with metro works progressing also in Sao Paolo, Brazil; Quito, Ecuador and Lima, Peru. Buenos Aires in Argentina has progressed an extensive programme of wastewater and flood control management and with works also to replace a suburban railway line underground. Alto Maipo in Chile led the development of several hydro developments in South America, with Chile also leading the introduction of TBMs for developments in the mining industry. For transport links through the Andes, project continue to develop for the Agua Negra highway for Argentina, Chile and Brazil; the Tren a las Nubes, or Train to the Clouds project in Argentina on a route to Chile; and the Bioceánico Aconcagua baseline railway between Argentina and Chile that includes a 52.5km-long twin-tube connection. ■


Effluent outfall, Buenos Aires, Argentina, 2019

Overheating metros

Calvin R Barrows,
BSc (Hons), CEng, MICE

Overheating in underground metro systems is a serious and concerning issue, particularly as the numbers of passengers using older and deeper systems increases. A cost effective method of addressing the issues is painting trains with high-performance solar reflective paint and fitting low emissivity glass windows for lines that include both surface and underground track.

There are many heat sources in metro systems that have above and below ground sections and significant differences in operations during winter and summer (Fig 1). In cooler weather, the combined effect of the non-seasonal heat sources is insufficient to heat trains to a comfortable level without additional heating systems. In summer the outside ambient air temperature and solar irradiation increases temperatures in trains. While ambient air temperature varies throughout the daily cycle, the considerable increase in train temperatures on the surface is due primarily to the role of solar irradiation.

When the sun is at its zenith, direct sunlight at earth surface is about 1050 W/m^2. The power of the sun is affected by the angle of incidence. At a 45° angle of incidence, although solar radiation can cover a 40% greater area, it is 30% less intense than when at its maximum angle of incidence of 90°. How this changing intensity affects trains also needs consideration.

How much of the train should be coated with solar reflective paint is for consideration. Focusing on the roof alone will limit potential benefits. The average carriage size is 2.9m wide x about 2.5m high. Taking that as a basis, when the sun is at its zenith, it produces 1,050 W/m^2 x 2.9m/m length of carriage or 3,045 W/m (3.045 kW/m) on its roof. With the sun at a 45° angle of incidence, and with the sun on both the roof and one or other side of the train, there is approximately 2.5m + 2.9m of train body exposed to the sun. At this angle the sun intensity is 1,050 W/m^2 x 70% (30% less than at its zenith) = 735 W/m^2, but this is now shining on 5.4m/m length of train body. In this scenario, the sun produces 735 W/m^2 x 5.4m/m length of carriage or 3,969 W/m (3.969 kW/m) of solar irradiation heat.

The benefits of adding high-performance solar reflective paint on train bodies to reflect solar irradiation will:

- Reduce internal train temperatures in summer;
- Reduce the size of air conditioning systems, delivering greater payload and reduced weight;
- Reduce in-train air conditioning running costs;
- Improve the passenger experience in terms of comfort; and,
- Reduce the safety risk to passengers in a stalled train event.

Similarly, in the context of reducing tunnel heat, reflecting the solar irradiation when travelling on the surface in summer would:

- Reduce the external skin temperature of the train and the absorbed heat emitted from the train body into the underground system;
- Reduce the internal temperature of the train, and the heat being discharged from the train air conditioning system, on entry into the tunnel; and
- Subsequently reduce the heat transferred across the network from hotter lines to cooler lines by the pressure/suction wave caused by the moving trains.

With solar reflective paint on trains, the operation of adequate and comprehensive cooling systems in underground environments may become less crucial and may obviate the need to install them at all. Monitoring the external skin of a train might best be achieved with sensors on the internal face of the external skin and suitably insulated from the train's internal space. Monitoring of undercarriages and bogies would need some serious thought to be able to identify the effects of the various heat sources operating on these.

With every additional treated train, the network, the cumulative reductions on tunnel temperatures, and thus sub-surface network temperatures, would become significant. The fullest benefits will only become apparent when all lines have had all their trains treated.

The effect of solar gain through glass windows is well known. The next logical step would be to fit low emissivity glass windows on all trains. Given the high percentage of window glass in the body of a carriage, using highly reflective glass would prevent the absorption of external solar heat while the train is on the surface.

In an era of heightened and pressing environmental concern, the application of solar reflective paint and the incorporation of highly reflective glass windows is cost-effective, particularly when compared to the capital cost of installing mechanical cooling solutions. In the longer term it would deliver real on-going reductions in maintenance and energy running costs. ■

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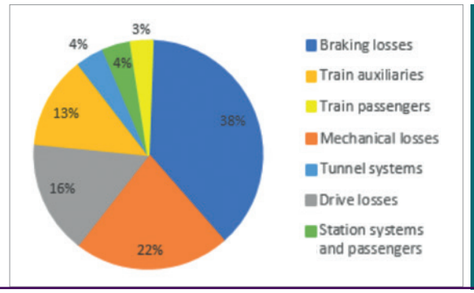
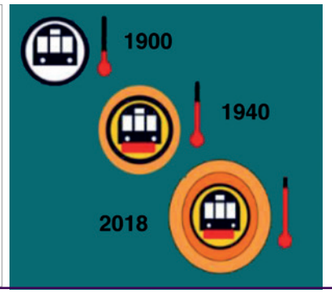
Left: Fig 1. Sources of heat generation in the London Underground;
Right: Rising temperatures with increasing depth of the network over the years





Using metro heat

Jonathan Rowland, *TunnelTalk*

Turning underground metro lines into heat-recovery systems

Systems to capture heat generated in metro system tunnels to supply municipal heat networks is a research project by the Swiss Federal Institute of Technology (EPFL). Researchers have for the first time estimated precisely the coefficient that allows them to establish the amount of heat that the air contains. Called the convection heat transfer coefficient, it defines the rate of heat transfer between the airflow within a tunnel and the surrounding ground. A higher convection heat transfer coefficient could therefore imply a higher potential for heat recovery.

"A good estimate of the convection heat transfer coefficient is essential, as it can affect the final thermal potential," said Margaux Peltier, a researcher at EPFL.

Researchers found that, "constant values can be used to describe the overall heat transfer phenomenon in underground structures, regardless of their cross-sections." In contrast, the roughness of the walls was found to have a greater impact, "leading to higher values and increased heat transfer rate," said Peltier.

The scientists applied their research to the new 4km M3 metro line in Lausanne. According to studies, fitting a heat recovery system along 50-60% of the planned route would cover the heating needs of 1,500 x 80m^2 apartments. In addition to providing heat during the winter, the system could be reversed in the summer with heat taken from the surface and stored underground.

One of the first pilot installations was in Vienna and more recently, an underground station was equipped with a heat-recovery system in Geneva. The application has also been tested in the Crossrail project in London. ■

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Interest in hyperloop on the rise

TunnelTalk reporting

Plans to develop hyperloop high speed transportation networks are coming closer to reality following progress in India, the Middle East, Europe and the USA.

Support in the USA has led to the formation of the Non-Traditional and Emerging Transportation Technology (NETT) Council, the creation of the Missouri Blue Ribbon panel and a visit by Federal Government House Transportation and Infrastructure Chairman Peter De Fazio to the hyperloop test track in Las Vegas, Nevada.

"I believe we could see a hyperloop in operation in the USA in years, not decades," said Virgin Hyperloop One Co-Founder Sir Richard Branson.

The NETT Council, set up by USA Secretary of Transportation Elaine Chao, will work to identify and resolve jurisdictional and regulatory gaps to help bring the technology to commercialisation.

While some components of hyperloop are similar to rail, others, including cabin pressurisation, are similar to aeroplanes. Virgin Hyperloop One has tested its technology successfully at full scale at its Nevada test site using electric propulsion and electromagnetic levitation under near-vacuum conditions to create a faster mode of transport at speeds of up to 1,200km/hr.

The company is now working with governments, partners, and investors around the world and currently has projects underway in Missouri, Texas, Colorado, the Midwest (Figs 1, 2 and 3), India, and the UAE.

The concept of hyperloop envisages excavation of extensive underground networks. Such underground hyperloop systems are viable only if the cost of tunnelling is reduced by a factor of ten or more.

Taking note of this, the British Tunnelling Society (BTS) of the Institution of Civil Engineers (ICE) in the UK has set a challenge to investigate the feasibility and practicalities of building a hyperloop system for the UK.

The BTS Hyperloop Challenge will look at the technical implications and advantages of building tunnels for hyperloop systems and at the cost drivers of tunnelling and the feasibility of cutting those costs by excavating smaller diameter tunnels, doubling the power of tunnel boring machines, using a continuous excavation and lining process, investing in R&D and taking advantage of economies of scale.

The Challenge project, partly funded by the ICE Enabling Fund, will comprise a report to be carried out by UK consultant firm London Bridge Associates.

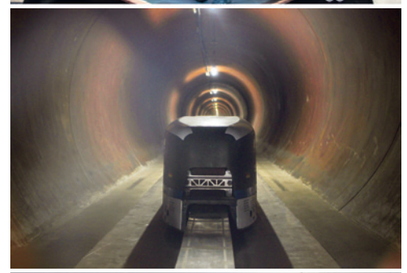
"There is already considerable enthusiasm to participate in the Challenge both within as well as outside the tunnelling community," said BTS Project Director Bill Grose. Simon Morgan, Managing Director of London Bridge Associates, said: "This is an opportunity to bring together industry knowledge and experience to show how the tunnelling industry can take a lead in the implementation of a hyperloop concept and maximise the benefits of the underground environment."

In France, Virgin Hyperloop One (VHO) is working with the French Independent safety assessor Certifer and is poised to start a first-of-its-kind safety assessment of the system to meet the goal of surpassing the safety of all existing transportation systems. The assessment will ensure that hyperloop complies with transportation guidelines regarding civil and mechanical works, guideways, control command and signaling, and magnetic propulsion.

"Partnering with Virgin Hyperloop One aligns with our mission to support clients exploring innovative solutions to set the future foundations of intelligent, reliable and safe transportation modes," said Pierre Kadziola, Certifer CEO.

"Governments are looking to us to advise on this technology sector and recommend a new set of global standards," said Benjamin Pasquier, VHO Director of Safety Certification and Quality Assurance.

From top: Sir Richard Branson (right), a champion of hyperloop; Hyperloop concepts suggest supersonic travel in vacuum tunnels; VHO aims to become the safest mode of transportation



Contribution to sustainability

Hyperloop is catching the attention of environmentalists, as the system could be up to 10 times more energy-efficient than short haul flights, 50% more efficient than high-speed trains, and energy-neutral (off-grid), according to VHO.

At speeds of more than 1,000km/hr, hyperloop could connect all Gulf cities, for example, within an hour from each other. The system has zero direct emissions and could move close to 45 million passengers/year in the region using solar energy.

"As cities around the world feel the impacts of climate change, we need viable solutions," said Jay Walder, CEO at VHO. "Transportation is one of the biggest areas that needs to be addressed and we are committed to a massive leap forward to offset the impacts of vehicle, train and air travel in a way that no current technology can." ■

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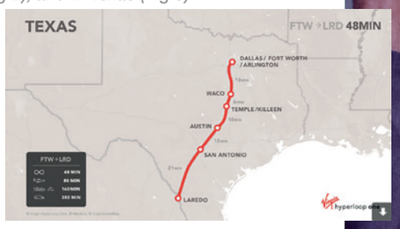
From left: Proposed Virgin Hyperloop One routes in the USA in Missouri (Fig 1); the Midwest (Fig 2); and in Texas (Fig 3)



Equipping TBMs for tough conditions

Shani Wallis, *TunnelTalk*

Predicting trouble ahead; preventing EPB clogging; mixed conditions in hard rock faces; machine learning for autonomous TBM operation; disc cutter design, and much more were topics discussed during two informative days of conferencing at the 2019 TBM DiGs conference. Convened by a team of the Colorado School of Mines, under the chairmanship of Jamal Rostami, a small number of highly-knowledgeable delegates profited by the specialised single topic themes of the two day programme.

In his opening keynote presentation, Professor Herbert Einstein of MIT, Massachusetts Institute of Technology, demonstrated that much can be predicted about the conditions to be expected on a tunnel heading from information available from historic data, alignment geological site investigation and before facing both natural and human error risks. By illustration, a project was cited where predictions called for a TBM to move from open to closed mode operation. The change did not take place and face loss and surface settlement were the consequence.

Among several questions, *TunnelTalk* asked: given that the consequence as described occurred within the TBM advance of one ring, could the operation of the TBM be programmed to react automatically to the predicted or detected changes in geology. The answer came from another delegate in the audience affirming that the possibility is already available on TBMs. Richard McLane of Traylor Bros explained how interlocks, as they are called, are programmed into the TBM PLC, programmable logic controller, to bring TBM operations to a stop automatically if, for example, pressure in the excavation chamber falls below a trigger value or if continuous backfill of the annulus behind the segmental lining is interrupted. The concept has been used on project TBMs for several years, added McLane, but that it is not applied as industry best practice. Professor Einstein concurred that artificial intelligence or machine learning is the way forward and will become more sophisticated as technology and big data collection and management improves with time, research and development.

To advance the discussion, Ulrich Meidl of Germany, in his keynote, explained how much information can be gathered by current sensors and monitoring systems. "This is now truly impressive, and especially with the added capacity of cloud computing," said Maidl. "Systems that monitor TBM operating parameters alone can deliver more than 1,000 items of data every two minutes. Add to this the information from settlement monitoring networks and logistics management systems, the collection can run into the several thousand pieces of data. From all of this data we need to combine big data with human engineering to arrive at the analysed parameters that are of importance to the daily operation and management of a TBM project. This will be more than using the technology as a black-box recording of data for back analysis as it is today."

Discussion about the possibility of automatic TBM operation included the system developed by the MMC-Gamuda team in Malaysia for autonomous operation of the Herrenknecht variable density TBMs engaged currently on Line 2 of the KVMRT Metro in Kuala Lumpur.

While the discussion contributions ranged from those who fully embrace the technological possibilities to those who warn be careful what you wish for, the team from Malaysia confirmed that it is precisely during high risk reaches that operation of the machines is taken away from the human and given over to machine intelligence. "The human operator takes too long to appreciate something has changed and too long again to decide the solution, and them to react," said a representative of the MMC-Gamuda development team. "Intelligent systems for autonomous machines, operating with all the data available, can compute the situation in seconds or milliseconds and react equally as fast." It was suggested also that this will solve the issues of training skilled TBM operators and addressing the critical shortage of skilled TBM operators in the global industry today.

Difficult conditions presented by hard rock geology gave rise to interesting discussions. This started with a suggestion by Björn Nilsen and Pal Jakobsen of the NTNU University of Science in Trondheim, Norway, that there can be mixed face conditions in a hard rock TBM heading, conditions where rock of different compressive strengths and qualities can be present across the same face. Such conditions can cause damaging impact for cutters and TBMS during excavation.

Don Del Nero of the USA followed up and opened his address about abrasive conditions with a quote by TBM consultant Richard Lewis that "wear can add the same price as the TBM again to a project." Del Nero went on to explain that quartz is harder than most manmade steels and that:

- the quantity of quartz on a TBM job should be included in the GBR geotechnical baseline report;
- the composition of cobbles and boulders should be a baseline item, not just their predicted number;
- there should be a licensed geologist on every tunnelling job;
- international bodies such as the ITA or the ISRM should work on developing universal standards for testing and reporting of abrasivity;
- that, while carbides are the best anti-wear metals at present, new materials such as cermats are being developed; and that
- research and development of cutter tool life x ground abrasivity is coming up with some far-reaching disc cutter design ideas to assist also disc operation on mixed face, multi-mode TBMs.

Sindre Log of The Robbins Company added to the cutter discussion and answered a *TunnelTalk* question about the regularity of changing worn or damaged cutters, either one at a time as necessary, or several during a planned maintenance period. He confirmed that there are advantages of changing all cutters for a complete new set, but that other considerations, such as extended downtime, can cancel or neutralise the benefit.

The performance of the disc cutters also affects the possibility of recycling excavated material as concrete aggregate, as discussed by Robert Galler of Leoben University and the ZAB Underground Research Centre of Austria. Too much grinding into fines reduces the value of the excavated material and the efficiency of processing excavated material into aggregate.

Staying with hard rock TBM operations, the realities of high-volume, high-pressure ground water ingress into a TBM heading, and the efforts of using grout injections to stem the flow, was the topic of an informative presentation by Knut Garshol from Norway. Probing and the cycles of pre-excavation grouting were discussed with the recommendation that shorter arrays with more frequent overlaps for pre-excavation grouting is more effective than trying for 100m long grouting arrays.

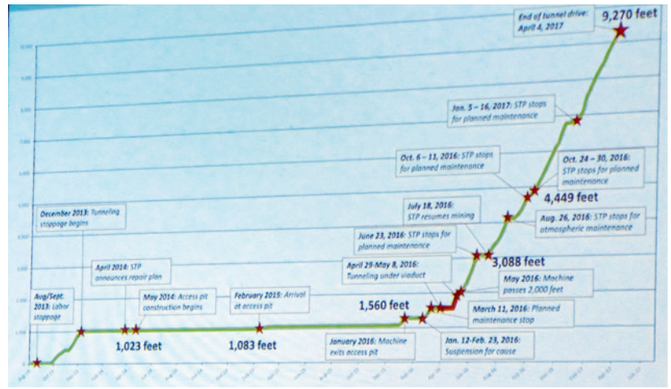
A full afternoon session was given over to presentations about the experience of the mega Hitachi Zosen EPBM for the SR99 Alaskan Way viaduct replacement highway tunnel in Seattle – not about the cause of the breakdown or two year repair process, but from the restart in January 2016 through to breakthrough on 7 April 2017, achieving up to 14 rings per day and completing 8,186ft of 17.48m o.d. excavation and segmental lining to 15.54m i.d. in 452 calendar days and 195 excavation days.

Keynote speaker Juan Luis Magro, Construction Manager for Dragados and for the Seattle Tunnel Partnership construction JV, quantified some of the remarkable statistics associated with a TBM of 17.5m o.d. including an excavation volume of 1,000 tons or 675yd³/shove for the 2.1m wide ring of segmental lining; that 7,000 tags were feeding to the PLC data logger every three seconds from the TBM monitors and more than 2,000 instruments on the alignment; that the cutterhead was dressed with 743 cutting tools, 106 of them able to be accessed and changed in hollow atmospheric arms of the cutterhead; that there were 272 dives during a total of five hyperbaric interventions; that settlement for passage under the viaduct was predicted at 0.25-0.95cm and was actually limited to 0.08-0.25cm and that, at the end of the process, it was proven that super-sized TBM dives under urban areas and high-rise city centres is possible. "It can be done."

There were many questions in follow up about settlement control, soil conditioning, the selection of EPB technology over a slurry TBM alternative, and the management of fewer than expected boulders. It was an enlightening exposé into the operation of mega EPBMs and the many parameters to be controlled for success.

Taking a large diameter soft ground TBM through a tight S curve alignment was the paper by Professor Mistutaka Sugimoto of the Nagaoka University in Japan. Special liner plate segments of about 25cm wide were used for the curves and when asked by *TunnelTalk* if special needs were required of the TBM tail seals the answer was no, that the four wire brushes and lots of tail seal grease managed the seal through the curves.

The discussion went on to the sealing of the articulation joint, and while Brian Khalighi and Matthew Greger of Robbins described systems applied by Robbins to seal the standard straight overlap articulation joint, Professor Sugimoto described a knuckle type articulation joint which, he said, is easier to seal.



SR99 mega TBM advance to breakthrough in Seattle

Of particular interest in the presentation about operation of the mega Robbins slurry TBM for the Hiroshima highway project in Japan, was the information that vacuum segment erectors are not permitted by regulation in Japan. Instead, Greger of Robbins detailed the design and operation of the lock-in mechanical pin erector system for lifting and placing the mega-sized precast segments.

Hyperbaric intervention was the focus of the keynote address by Werner Burger, Chief Engineer for Herrenknecht, described the high pressures acting on the underwater drives for the Lake Mead intake tunnel in Nevada; the Eurasia subsea highway under the Bosphorus in Turkey; and the Tuen Mun-Chek Lap Kok subsea highway link in Hong Kong. Burger explained how certified hyperbaric divers lived for up to 28 days in compressed air conditions to be shuttled down to the TBMs to complete their maintenance shifts in the excavation chambers. *TunnelTalk* asked if an operation similar to the Project Moses on the Storebaelt railway project under the sea in Denmark in the 1990s, that installed a dewatering system on the seabed to lower the ground water pressure ahead of the TBM drives, had been considered to lower the hyperbaric pressures on these extreme TBM drives. The answer was that the ground conditions on the recent projects was too permeable and a seabed dewatering system prohibitively expensive in scope and operation.

An appropriate wrap up of proceedings was presented by Brian Fulcher of the USA who, as Animateur of the ITA Working Group 14 on Mechanised Tunnelling, explained how the Working Groups of the ITA provide the international forum in which many of the suggestions for investigation are being progressed, and through which the reports of the Groups are freely available for pdf download on the ITA website. In response to a question from *TunnelTalk*, Fulcher confirmed that the Working Groups – 23 in total and covering a wide range of specific topics – are open to all who are interested. "Being a Member of the ITA or a member of a Member Nation delegation is not a prerequisite," he said. "Anyone in the industry is welcome to become involved in the activities of the groups. It is by expanding the pool of experience and contribution that the best for the industry as a whole and internationally is achieved." ■

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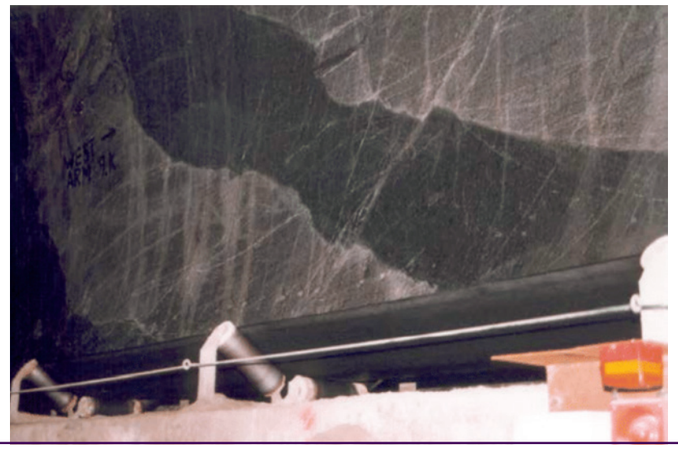
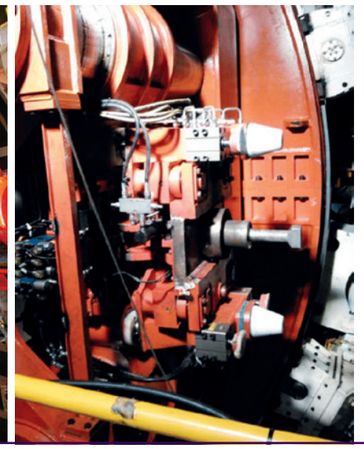
Mixed face intrusion in a hard rock mass



A hydraulic pin, that inserts and twists, is the key to the mechanical segment erector on the Hiroshima highway Robbins TBM in Japan



Road to litigation and possible bypasses

Shani Wallis, *TunnelTalk*

Litigation is an agreed blunt instrument and last resort for settling disputes in the industry, but what is it that drives the parties to litigation, when all starts out so positively - with the best of all possible support tools written into the contract and all the risk scenarios and alternative dispute resolution considerations assessed, evaluated and agreed.

Traditionally it has been the ground, via differing site conditions, at the heart of disputes. Other causes for contracts ending up in court include non-performance, incompetence, intractability, schedule pressure, cashflow crises, and recovering from natural or accidental disasters.

Another is the effort in recent decades by project clients to transfer all or most risk involved with projects to the contractor. This has been highlighted by the introduction of different types of contracts including design-build, EPC engineering, procurement, construction, and concessionaire contracts and their variations. These have the contractor and its engineering firm in the lead for decisions concerning means and methods, detailed design to end-product performance criteria, and managing programme and schedule.

This transfer does not abrogate the client entirely. In all accepted norms, the ground still belongs to the owner, and it remains a party to the contract and to any disputes that may arise. This has led to development support processes as an arbiter between paymaster (the client) and functionary (the contractor). Processes such as geotechnical baseline reports, geotechnical data reports, risk registers, independent expert panels, delivery partner organisations, dispute review boards, and their variations have been developed to mitigate this transfer of risk responsibility.

The transfer of risk is also having an influence on the construction and insurance industry. Contractors are at a point where they refuse to bid projects in certain jurisdictions or under certain circumstances. The accepting of more risk by contractors must drive contract bid prices up and are contrary to competition to drive prices down. For insurers, the industry is again becoming averse to underwriting the perceived growth of risk-taking in the industry and financial institutions are shying away from support of underground construction projects when surface alternatives are available, even if the surface option is more disruptive to urban or green space, or more expensive in long-term life-cycle costs.

The increase in litigation is a concern in itself and while no observer or reporter, or even some closely associated with any project in a dispute, can know of, or be privy to, all the details and circumstances of a case – and while no case verdict can set precedent or guarantee the outcome of a future similar case – the overall situation is leading to serious dilemmas for underground infrastructure creation. These issues need to be shared and a common framework found for securing support for future projects.

As well as disputes between clients and contracts, there is also the influence of politics and politicians that can knock the industry sideways. The worst aspect of politicians as arbiters of major infrastructure projects is that their terms are limited and subject to the opposition taking over at the next election. Political support and championship of a major project can simply evaporate overnight and result in cancellation of projects, termination of contracts, unnecessary delay to needed infrastructure and the increase in cost that delay causes.

A famous or infamous example of such a situation was the cancellation of the ARC, Access to the Region's Core, project between the New Jersey and New York States in 2010. Twenty years later, the State Governments are looking at the same project under a different name (the Gateway project), for about the same price of USD$11.3 billion to $12.7 billion for the new rail tunnels under the Hudson River into Pennsylvania Station. The commuters have suffered the congestion on trains in the meantime, and the services in the existing 100-year-old rail tunnels that are in urgent need of repair have continued to operate without upgrade attention.

The SR99 highway tunnel in Seattle, USA, also suffered political intervention. The Washington State Governor, Chris Gregoire, who supported the publicly funded, double deck highway tunnel as the viaduct replacement, and signed its procurement contract in her second term, was replaced by Governor Jay Inslee in 2013. The new Governor took a hard-line approach to the contract, paraphrasing the approach as 'we have a watertight fixed-price contract and we will hold the contractor to it'. With that approach, any out-of-court settlement to the dispute between client and contractor was unlikely (see p58).

Politicians can also do an about face when acting on promises to the electorate. In Malaysia, when a newly elected administration in 2018 threatened cancellation of the Klang Valley Metro Line 2 in Kuala Lumpur, the day was saved only when the delivery partner JV agreed to lower costs by cancelling full scope parts of the Line 2 project – deferments that may well cost substantially more to complete at a later date and under separate contract.

Public authorities also make rules that seem to be able to be overlooked when it suits, frequently leading to objections to the preferred bidder. High profile cases include the objection to the award of the Los Angeles Purple Line contract and the concession contract for the Silvertown highway tunnel under the River Thames in London.

In efforts to take the industry forward there have been many attempts to rewrite the form of contract. The most recent is the Emerald Book, a collaboration between FIDIC and ITA to develop a form of contract that is specific to the underground construction industry.

Principle to the endeavour is to address the issues of:

- Allocation of risk
- Disclosure of all available geological and geotechnical information
- Inclusion of a contractual geotechnical baseline
- Inclusion of a tailored Unforeseeable Physical Conditions clause
- Implementation of a ground classification system and of supporting particular conditions that properly reflect the effort of excavation and stabilisation
- Time for completion to be largely influenced by ground conditions
- Provision of a flexible mechanism for remuneration according to ground conditions, foreseen and unforeseen.

It may well be the most advanced consideration of contract set up in recent times and better than the tools that supported earlier forms of contract including:

- Partnerships
- Alliances
- PPPs and
- Inclusion of alternative dispute resolution.

An important, and perhaps underestimated, party to any underground infrastructure project is the insurance underwriter. It is a business, for sure, but is the business designed to underwrite incompetence or coverup. The premiums for insurance coverage are high, but the pay out, if assured and agreed, can be also very high. The consequences of high pay outs for high risk coverage in the tunnelling industry are well known and it was the impasse between the industry and the insurers after the Heathrow Express collapse in the UK in 1994 that the industry introduced the Risk Register Code of Practice. Initiated by the UK BTS (British Tunnelling Society) and the ABI (Association of British Insurers), the initial Risk Management of Tunnel Works has grown into the International Joint Code of Practice for Risk Management of Tunnel Works that covers the minimum requirements for securing insurance coverage for any underground infrastructure project.

Still, for the insurance industry, underground works are high risk projects and carry potentially high loss pay outs.

Where the first case of the contractor versus the owner of the SR99 mega-TBM drive project in Seattle has extracted a verdict for the owner, the case of the contractor versus the insurance provider is yet to be heard and verdict yet to be known. Whichever way that case is decided, the SR99 verdicts and their appeals will again be landmark decisions that will shape the contracting and underground project procurement industries for the decades to come. ■

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Tailor-made TBMs for hard, hard rock

Arnulf M. Hansen, Fredrikke Syversen and Steinar Johannessen, Bane NOR, Norway, Amund Bruland, NTNU, Trondheim, Norway

TBM tunnelling in hard rock conditions is associated with high risk related to advance rate and cutter consumption. To cope with extreme hard rock challenges anticipated, as on the Follo Line railway project in Norway, a robust TBM design is imperative.

The project includes 20km of twin-tube single-track tunnels with 18.5km excavated through hard to extremely hard rock by four TBMs. Bane Nor, the state-owned company and owner of the project, awarded the contract to the Acciona/Ghella JV (AGJV). The 9.96m diameter double shield TBMs, to erect the segmental lining, were manufactured and supplied by Herrenknecht.

The rocks along the alignment consist of Precambrian gneisses with bands and lenses of amphibolite and pegmatite with several intrusions. The rock mass is quite homogenous and competent with moderate jointing and a UCS in the range of 100MPa to 300MPa. The expected advance rate, according to the NTNU Prediction model, was 15.6m/day[1].

Hard rock TBM design

Based on field data from more than 250km of hard rock tunnels, the NTNU, Norwegian University of Science and Technology, implemented important design principles for hard rock TBMs[1].

During rock breaking under a disc cutter, efficiency is characterised by the size and shape of the largest chips, and by the amount of fines produced (Fig 1). For a given rock mass, rock-breaking efficiency may be increased by increasing the applied cutter thrust force and/or increasing the number of cutters on the cutterhead.

For individual disc cutters, the trend has been to increase the cutter bearing size and the cutter ring diameter in order to apply higher cutter thrust. Standard cutter diameter for hard rock conditions has been 19in, with 20in a possible next step. Design of the cutter ring itself relies on current steel technology. A constant cross section type is used, with cutter ring edge width varying from 15mm to 25mm. A cutter in the outer part of a cutterhead will have a higher rolling velocity and is exposed to higher peak loads than an inner cutter. Hence, a wider ring is needed to avoid destructive wear.

The spacing between adjacent cutter tracks influences the necessary thrust to break large chips and the larger the spacing, the higher the necessary thrust (Fig 2). Rock breaking work increases with the square of the radius from the centre of the tunnel face and outwards. Spacing between cutter tracks must therefore decrease towards the gauge. Tip width of cutter rings should be as narrow as possible to obtain a good rate of penetration. The tip width of the ring should be sufficient to sustain the cutter loads needed to cut the rock efficiently without cutter ring chipping or mushrooming.

For the Follo Line TBMs, the contractor found that a low Rockwell hardness of the ring for hard rock results in mushrooming where the ring tip width becomes so wide that penetration per cutterhead revolution is reduced, causing under utilisation of the full TBM potential.

First of four TBMs ready for launch
(Photo by Acciona/Ghella JV)

Mapping a TBM rock face

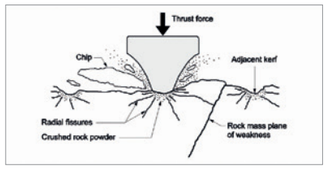

Fig 1. Rock breaking under a disc cutter

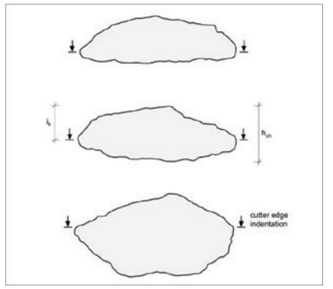

Fig 2. Cross sections of chips with increasing rock breaking efficiency from upper to lower chip

Cutter numbers and layout

When considering rock-breaking efficiency and cutter wear only, the ideal cutter layout pattern would be to place all cutters along one diameter line of the cutterhead. However, such a design would generate extremely high and unbalanced forces on the cutterhead structure and on the main bearing. The seemingly best alternative is to apply alternating cutter placement along the two arms of a double spiral starting in the cutterhead centre.

Generally, the total number of cutters on a cutterhead intended for boring in hard rock conditions should correspond to an average cutter spacing of approximately 70mm over the cutterhead. In extremely hard rock conditions, consider having more cutters on the cutterhead in exchange for smaller openings for muck removal.

Steel in the cutterhead

Boring in hard rock is associated with strong vibrations originating from the high peak loads of the rock breaking process. These strain the cutterhead structure, especially the cutter housings. The simple solution is to add structural strength using steel.

The stiffness of the cutterhead structure is improved by more steel. Increasing the hydraulic stiffness will increase the diameter and/or the number of the thrust cylinders.

Main bearing

The main bearing will have to respond to high and unbalanced load situations. Considering the total rock-breaking work of the tunnel face, half of the work will be outside 0.7 of the cutterhead radius. The cutter peak loads will increase towards the gauge due to the higher rolling velocity of the cutters and the curvature of the cutterhead structure. Hence, the main bearing diameter should be in the range of 0.7 of the cutterhead diameter.

Babendererde Engineers of Germany performed a third party verification of the main bearing L10 life calculation for the proposed 6m main bearing of the Follo Line TBMs according to ITAtech Report No 1[3]. To minimize the risk of main bearing failures during excavation, the Follo Line management entered into an agreement with the contractor to enlarge the diameter of the main bearing to 6.6m o.d., which gave a main bearing to TBM diameter ratio of 0.66

At the end excavation in February 2019, these upgrades proved to be justified. ■

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TBMs designed for excavations on the moon

Jamal Rostami, Earth Mechanics Institute (EMI) and Chris Dreyer, Center for Space Resources (CSR), Department of Mining Engineering, Colorado School of Mines; Ruben Duhme, Herrenknecht Asia Headquarters, Singapore; Behzad Khorshidi, McNally Construction, Canada,

To prepare for human staging on the moon as a base for travelling further into space, engineers from the Colorado School of Mines, TBM manufacturer Herrenknecht, and construction company McNally of Canada, are considering the challenges of developing a lunar TBM (LTBM).

Underground bases on the moon would protect lunar inhabitants and equipment from the harsh environment at the surface, including the vacuum environment, impact by meteorites, radiation, extreme temperatures, storms, and other unknown conditions.

Developing rilles, which are ancient lava flows that formed into hollow structures, could create underground spaces to house bases the size of large cities with tunneled interconnections (Fig 1).

Tunneling could also access and extract water ice, carbon dioxide, and other volatiles present in and near the lunar north and south poles. LTBMs could also be adapted for the frozen regolith, the layer of material covering the solid rock, in the permanently shadowed craters at the lunar poles.

An LTBM has been proposed before and an early conceptual design developed[3]. It is new discoveries about the moon and recent advances in TBM technology that call for re-examination of the possibilities of building structures on the moon.

Lunar geology

The geology is expected to be a 10m layer of regolith, highly compacted within the first 10-20cm, with boulders and fractured rock, deeper intact bedrock, basaltic in the Mare regions and anorthositic in the highlands. Frozen regolith at the polar regions would combine fine grained to coarse grained rock including boulders of anorthosite mixed with icy volatiles, creating a permafrost region with variable mechanical strength.

Excavation face conditions will be mixed with more challenging conditions at the polar regions and through boulders and bedrock, requiring high cutting forces that cannot be supported by the weight of equipment on the surface.

Some of the challenges of using TBMs on the moon include:

Weight limits: A 2m to 3m diameter TBM can weigh more than 100 ton, based on using steel for the support structures and components. Alternatives are needed to reduce weight specifically for transporting equipment on rockets. The primary support structure could be manufactured from lunar resources such as cast basalt or compressed sintered regolith reinforced with metallic members or basaltic tensile fibers. Using carbon fiber composite parts and lighter composites or alloys for various parts of the machine is a possibility. New materials will have implications on repairs and maintenance such as welding of the parts.

Temperature: Most metals are brittle at temperatures below 50°C. Surface temperature on the moon varies from about -190°C to +120°C at the lunar equator. It is ±3K at 30cm beneath the lunar surface and there is no variation below 700mm. Materials for seals and lubricants will be critical to success. Graphite could be a lubricant.

Power and energy consumption: Lunar TBMs may require excavation techniques that are not economical on earth. High efficiency components should be employed wherever possible. Low friction bearings, high efficiency drive systems, and preventing power losses will all be a part of the equation. The use of nuclear or solar power could meet the demand for a typical TBM.

Abrasivity: Regolith and basalt are known to be abrasive. Regolith is reported to be jagged with sharp edges. As a result cutting tools and machine components will wear at much higher rates. The use of conditioning agents in the excavation chambers may reduce machine torque and wear.

Vacuum: The lack of atmosphere and working in a vacuum pose significant challenges. Putting a system in place where pressure can be built up inside the tunnel will be easier with operations entirely in hard rock. A sealed heading entrance and a design to support pressure will have three benefits:

- Capturing of valuable volatiles created during the tunnelling process.
- Enabling later use of tunnels to contain an atmosphere for human habitation.
- Allowing for use of earth-normal methods and operations.

Tunnel linings: There is recent development of a helical segmental lining system that allows continuous operation of the TBM while supporting the ground and sealing the heading for pressurized working conditions. This is accomplished by using an integrated gasket in the tongue and groove joints to prevent water ingress in terrestrial applications and for preventing air escape for working on a lunar application (Fig 2).

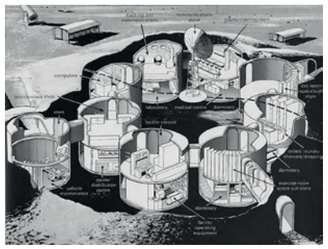

Fig 1. Large underground lunar base concept from National Geographic

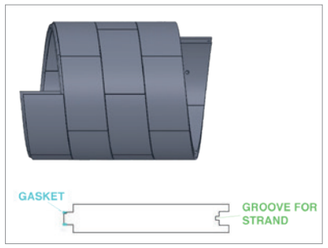

Fig 2. Helical segmental lining and sealing

Lack of convective heat transfer: Excessive heating of the cutting tools and components of the TBM drive system and other thermal management issues would be experienced. Human intervention maintenance of LTBMs would require space suits, which would limit the ability of workers to do their job. This will necessitate the clever use of automated systems and robotics to the greatest extent possible.

Lack of flushing/cooling material: Lack of atmosphere and of fluids means lack of flushing material for probing and installing roof bolts. There will also be no way of using fluids to dissipate heat generated by equipment motors and drive systems.

Ground stability and support: For lunar tunneling, support tools could be made from Kevlar or carbon fiber with light polymer or resin based cements sprayed on the tunnel surface. Special segments could be cast from light materials, such as 3D printed rock powder, to form air-tight rings and segmental linings could seal against water pressure.

Material transportation: A set of airlocks could allow the transition of materials in and out of the tunnel between vacuum and atmospheric pressure. Muck transfer could be as a fluidized particle flow by a gas supply on the LTBM.

Utilities: Electricity and compressed air lines to maintain atmospheric pressure to the heading would be the priority. Ventilation systems similar to those on the space station can function as the ventilation system, while the heat exchangers will make up for lack of heat transfer of ventilation in terrestrial tunnelling. Monitoring and communication systems are expected to function the same as on earth but need shielding against radiation at the portal. Trackless vehicles would transport men and materials.

Other issues: Ground investigation ahead of the machine would be a critical issue. Ground penetrating radar (GPR) is a possibility for geological probing. Geophones and similar sensors deployed ahead of the machine on the surface could also anticipate ground conditions using micro-seismic techniques. Another alternative is the use of smart probe drilling systems.

TBMs are a promising excavation method for establishing manned bases on the moon. Further research is required to meet the very specific challenges and offer a safe and efficient excavation operation. ■

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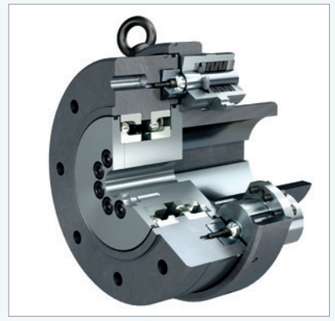
Torque limiters for cutterhead protection

mayr News Release

As TBMs work their way through rock and soil, like moving factories underground, every metre counts. A machine overload, caused through irregularities in the rock, for example, must not stop progress. "Our EAS®-HT torque limiters disengage the drive at a defined and traceable torque, to protect the motor, gears and drive line of the cutterhead from damage through overload," explained Ralf Epple, Product Manager at mayr® power transmission in Mauerstetten, Germany. In this way, long downtimes are avoided and the machines are operated sustainably. "The safety concept must not be susceptible to manipulation," emphasizes Epple. "The torque on our clutches is set on the manufacturer-side and is immediately accessible again after disengagement. The safety aspect is not dependent on recommissioning. The torque limiting clutches are reliable and dependable."

Reliable protection at the extreme

"The disengaging EAS®-HT clutches are element clutches that represent the ideal solution for extremely high torques and speeds, or large mass moments of inertia," explained Epple. These clutches are based on individual overload elements which are integrated into the flanges. The achievable torque results from the pre-tension force of the elements multiplied by the number of elements and the radius at which the individual elements are arranged. Due to the modular concept, not only clutches tailored to the respective application case can be built, but also far higher torques can be managed than with a central disengagement mechanism. mayr® power transmission offers the torque limiters from the EAS®-HT series in a standard version with a torque of up to 440,000Nm. The limits of what is possible,



Disengaging EAS®-HT torque limiters are reset immediately after rectifying an overload event

however, have not yet been reached, thanks to the modular construction. The possibilities are actually endless.

Non-destructive protection

In contrast to other overload systems, which work, for example, with pressurized hydraulic oil or shear pins, the EAS®-HT torque limiters are immediately ready for operation after the cause of an overload has been removed. The limiters are not damaged and can withstand several hundred overload disengage cases. It is possible also to trace at which torque the EAS®-HT clutches disengaged. "On other systems, the proof, so to speak, is destroyed after the overload occurrence, and uncertainty prevails regarding the disengagement torque," said Epple. Components destroyed, by systems unable to protect them, have to be replaced after an overload trip event. This generates costs and system downtime, and the replacement components have to be available in the spares inventory on site. Specialist knowledge is then required for recommissioning. "In that manual recommissioning, there is a risk of the torque being incorrectly reset," said Epple "and an incorrectly adjusted clutch makes no sense - the consequences are simply too high."

Replaceability, increased productivity

With regard to size and weight, the mayr® power transmission EAS®-HT torque limiters are ahead of the rest. "We have achieved weight savings of up to 50% in the new, compact units that are designed and further developed specifically for the tunnel sector. With this weight, and the compact outer diameters, the EAS®-HT torque limiters are ideally suited as a retrofit solution when existing systems are overhauled," said Epple. "And we have not forgotten to take the price into consideration. In some cases, our clutches are cheaper than other solutions."

Prior to shipment from the manufacturing plant, each clutch is extensively tested and set precisely to the required value, calling on decades of experience in development and design. "In the tunnel and mining branch alone, we have put several thousand torque limiters into use and have therefore gathered the appropriate experience with regard to the adjustment values," said Epple. "In addition, we receive positive feedback from the operators regularly. In particular, if existing systems have to be retrofitted, it is possible to increase their performance using our clutches. We often analyse the drive line together with our customers and, where necessary, can offer torque limiting clutches together with vibration damping systems." ■

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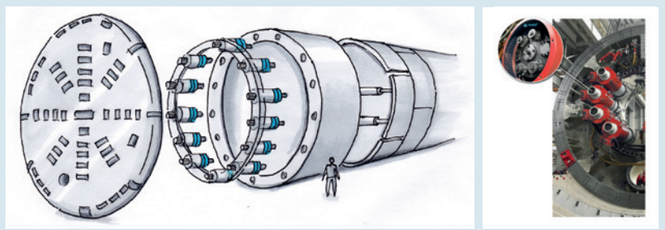


Left: Robust EAS®-HT torque limiter clutches on TBMs (in blue) can withstand extreme stresses and are easily accessed for simple re-engagement (right)

EAS®-HT torque limiters for TBM

Autonomous TBM operations

Shani Wallis, *TunnelTalk*

Fully automatic TBMs may be some way off, but the reality of autonomous TBM operation is already here. The system is based on custom artificial intelligence control algorithms analysing machine data in real time and assuming control of the various operational subsystems of the TBM with minimal human input.

Developed by a team of young engineers and technicians in Kuala Lumpur, Malaysia, the autonomous TBM operating system is more than a theoretical idea. The development team working, for the MMC-Gamuda JV on the Line 2 of the Klang Valley MRT system, has applied the system to 10 of the 12 TBMs excavating 13.5km of twin running tunnels under the city centre of the Malaysian capital. The 10 Variable Density Herrenknecht TBMs have had a separate industrial computer each added to their programmable logic controllers (PLCs) to provide autonomous operation, with human oversight rather than control.

The developers say that the proven success of TBMs under autonomous operation is preferred when operating under highly sensitive conditions and when the risks of human error would cause the most damaging potential consequences. They add that a machine fitted with the system will respond more quickly and more sensitively than a human operator when, for example:

- correcting line and level to steer the machine;
- adjusting the parameters of the TBM to maintain plenum pressures and the speed of the screw conveyor to avoid ground loss or over excavation and any subsequent surface settlement;
- controlling the speed of advance; and
- managing the slurry circulation in slurry mode operation.

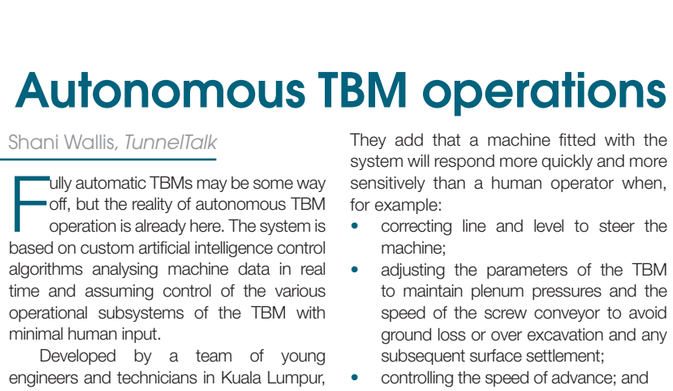
Autonomous operation of TBMs, from central oversight control centres, has been applied to the KVMRT Line 2 for the past three years. With that experience, the team entered the system as a nomination for the leading series of international industry awards – first the ITA Awards in the category of Technical Product or Equipment Innovation of the Year and secondly in the Tunnelling Festival Awards in the UK sponsored by the BTS (British Tunnelling Society) in the category of Innovation in Tunnel Excavation. Described by judges of the awards as a game changer for the global tunnelling industry, the system won the category for both – the ITA Award in November in Miami and the UK Award in early December in London. This is deserved recognition of the system and its developers.

Inspiration for the development of the system is the brainchild of Gus Klados, Director-Tunnels Management for the MCC-Gamuda JV.

"The genesis for the system came to me while working on the Marine Running Tunnels of the Channel Tunnel in the 1980s when I realised that the steering problems of the TBMs were always caused by drivers trying to interpret or understand what a computer screen was showing them regarding the position of the machine," explained Klados. "Each TBM operator had different levels of skill and different levels of operator success. I felt there had to be a better way."

It was while working on the Delivery Tunnel North of the Lesotho Highlands Water Project in Southern Africa in the 1990s, that a black box from ZED Instruments was applied to steer the Wirth TBM automatically and the system kept the TBM within +/-20mm on the designed tunnel axis for 19km.

In Kuala Lumpur, Klados challenged his team to produce an auto-steer system. With time, the team developed the Autonomous TBM System with AI capabilities. "We have a wealth of experience now in operating these autonomous TBMs and of debugging the systems over many kilometres. We can see the potential of many new possibilities and eventual fully automatic operation of tunnel excavation systems," said team member Justin Chin. ■



Steering accuracy between a human operator and Autonomous TBM Operation

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MMC-Gamuda team winning an award for the system (from left): John Lim; Gus Klados; Ng Hau Wei; Justin Chin and Liew Kit Shen

Artificial intelligence to assist asset management

Dynamic Infrastructure News Release

Live 3D views of major infrastructure assets, including underground structures, could improve significantly the ability of asset managers to address maintenance and operating issues. The technology uses artificial intelligence to compare archived images, including those from smartphones, drones and laser scans, with new images to build up a record of changes to the condition of assets and allow operators to detect defects and anomalies before they develop into major failures.

"Deficient tunnels represent a severe infrastructure challenge in the USA and worldwide," said Saar Dickman, co-founder and CEO of Dynamic Infrastructure. "Their poor condition leads to millions in unplanned expenditure, but until recently there has been no effective system that can quickly and precisely identify defects through the lifetime of an asset. Our system delivers monitoring and alerts that can better manage expenditure and help prevent the next collapse. We are bringing the data revolution to the decision-making maintenance processes."

Artificial intelligence for asset management

According to the Federal Highways Administration and the Federal Transit Administration, there are more than 350 highway tunnels in the USA, of which about 40% are more than 50 years old, while 5% are now more than 100 years old.

Dynamic Infrastructure was founded in 2018 by Dickman and Amichay Cohen and in collaboration with a group of industry experts in the USA and Europe. The company is already working on projects in the USA, Germany, Switzerland, Greece, and Israel for clients operating a total of more than 30,000 assets. ■

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Centre for realistic underground research

Robert Galler, Chair of Subsurface Engineering, Montanuniversität Leoben, Head of the ZaB-Zentrum am Berg project, Austria

Railway tunnel portals

Portal of the motorway tunnels

A new, cutting-edge testing facility in Austria, is designed and developed to provide a realistic environment for research and education in the underground sector. Research topics at the facility are diverse and include fire safety; geology and geophysics; geothermal energy; NATM and TBM technology; underground mining techniques; sustainability and the environment; concrete technology; ICT applications; measurement and analysis technology; and numerical simulation.

The new ZaB-Zentrum am Berg centre, ZaB, is situated in a disused part of the Erzberg iron ore mine in the Styria region of Austria, which proved ideal for the facility due to its existing tunnel system and its connections to regional road and rail networks. The facility comprises almost 3km of tunnels with different cross sections and varying overburdens of 217m to a maximum of 235m to facilitate research projects under various conditions.

The €30 million construction cost of ZaB-Zentrum am Berg was shared with €6 milllion contributions from the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology; the Austrian Federal Ministry for Digital and Economic Affairs; and the Montanuniversität Leoben University, with the remaining €12 million allocated by the Province of Styria.

NATM excavation of new areas of the centre have created twin tube, two-lane motorway sections, and a twin tube single-track railway line. Started in 2016, the tunnels are each connected with cross-passages with parts of the existing Pressler and Kerpely tunnels of the mine repaired to be incorporated into the facility.

Geology

The Erzberg mine site is located at the north edge of the northern greywacke zone with the lithology comprising essentially limestone; dolomite and ankerite; and Eisenerzer beds of shale and phyllite. The shale beds had been problematic during construction of the old northern tunnels and had been supported, whereas the limestone and ore-bearing limestones were stable without further support and only showed rupturing due to jointing.

The existing tunnels are predominantly damp with some dripping and isolated running water ingress, which was drained through the west tube of the rail tunnel. Starting at the south portal, the west tube of the rail tunnel joins the south tube of the road tunnel.

The rail and motorway portals are both situated on the same level, but are in distinct geotechnical conditions. In the area of the railway portal, long bolts had to be used to avoid slope stability problems. As this portal is situated in a wooded area, rock fall was not an issue. In the area of the motorway portal, it was necessary to construct an intermediate level to minimise rock fall.

Although geological strata were available for observation in the open cut mine levels of the 1960s, the construction team encountered a number of challenges in the new mined headings. These included fault zones, containing completely sheared materials, and open fault zones presenting an open width of about 1m. In the old galleries of the former underground iron ore mine, six challenging sections had to be reopened to connect them to the four new motorway and railway tunnels. This involved a substantial amount of manual work using small units of equipment.

Rescue training underground

Fire safety research

The test tunnels are equipped with extensive ventilation equipment to realistically represent the function of various ventilation systems in the event of a tunnel fire.

Several tragic tunnel fires that occurred around the turn of the millennium revealed that a lot more research was needed in the area of fire safety. Fires in enclosed spaces are characterised by rapid propagation and the sudden development of smoke gases. Air currents create an additional negative affect on fire behaviour. The efforts of emergency services are made extremely difficult and often seriously dangerous by the incandescent flame front, poisonous clouds of smoke and poor visibility conditions.

Fire safety investigations that take place in laboratories are of limited reliability and even tests that take place in existing tunnels cannot emulate a real catastrophe. Tests in existing tunnels are laborious and expensive since the tunnel has to be closed and traffic diverted. In existing tunnels it is only possible to carry out tests with a restricted fire load in order to avoid damage to the structure.

Extraction fans, for the removal of exhaust gases, and jet fans to influence the longitudinal air flow, are installed in the tunnels at Zab. Both longitudinal and semi-transverse ventilation can be simulated to study real fire emergency situations. ■

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Reopening the old galleries

Challenging geotechnical conditions

TUNNELTECH INNOVATIONS AND DEVELOPMENTS

Cracking of segmental lining investigation

Jonathan Rowland, *TunnelTalk*

The exact cause of cracks appearing in a section of segmental lining on an extension of the Izmir Metro in Turkey was a subject of investigation. The segments were reinforced with a combination of glass-fibre reinforced polymer (GFRP) and macro-synthetic fibres (MSF). The supplier of the fibre reinforcement was not disclosed.

Industry professionals told *TunnelTalk* that cracking could have been caused by a range of factors. "It could be that the segment was not properly designed," said Ralf Winterberg, Group Chief Engineer of synthetic fibre manufacturer BarChip. "It is not the type of reinforcement but the design and installation that is critical."

"It could indicate a misalignment of the tunnel segments or an area of higher pressure," added Jeroen Smet, Technical Sales Director of Adfil. "It could be something to do with the concrete itself. You should also consider that a TBM pushes on these segments with a force far greater than anything induced by the hydraulic or ground pressure. The moment a TBM is slightly out of alignment, there is a huge peak force on these segments that could cause cracking."

Neither BarChip or Adfil are involved in the Izmir project.

In Feedback, Charles Allen of OTB Concrete in the UK said; "The initiation of a crack is not dependent upon the reinforcement. Reinforcement only comes into play once the concrete has cracked. It is the ability of the concrete matrix alone to resist the initiation of cracks by its flexural strength. The only way the issue can be resolved is by a site inspection of the operational procedures, which might have been questionable. For example, if the support bearers are not in line in the segment stack, then bending moments can be induced into the segment causing it to crack."

Following publication of the article, further information was submitted via Feedback from an engineer in Turkey who knows the Izmir project and requested the withholding of his details for professional career reasons. "I read the information about this topic and can confirm the following additional information in efforts to be transparent in the application and success of new systems. This application in Turkey, of hybrid GFRP+MSF reinforced segments, is believed to be the first in the world.

"The casting of the hybrid GFRP+MSF reinforced segments began in March 2019 and were held in the stacking yard at the factory until end of June 2019 when they started being built into the tunnel. During fabrication, real scale tests of the segments and the rings were conducted, in addition to all necessary materials tests, and all were positive. There were no cracks observed in the segments while in the stacks. "After the cracks appeared in the rings as erected into the tunnel, further tests of the segments and the materials were carried out and all designers and engineers involved confirmed the same positive results.

"The twin tubes of the metro project in question are being excavated by TBMs supplied by two different manufacturers. Each tube had about 100m of NATM starter tunnel excavation. At TBM launch, the rings of segmental lining were erected by the vacuum segment erector of the TBMs as a false tunnel in the open space, supported internally and externally, and with the annular gap in the NATM starter tunnel backfilled using the TBM backfilling system. This is not an unusual process. It has been used at the start of TBM drives on many metro projects.

"The questions are, what was the quality of the ring build for the false tunnel and when was the annular gap backfilled once into the NATM starter tunnel, and what was the quality of the backfilling process.

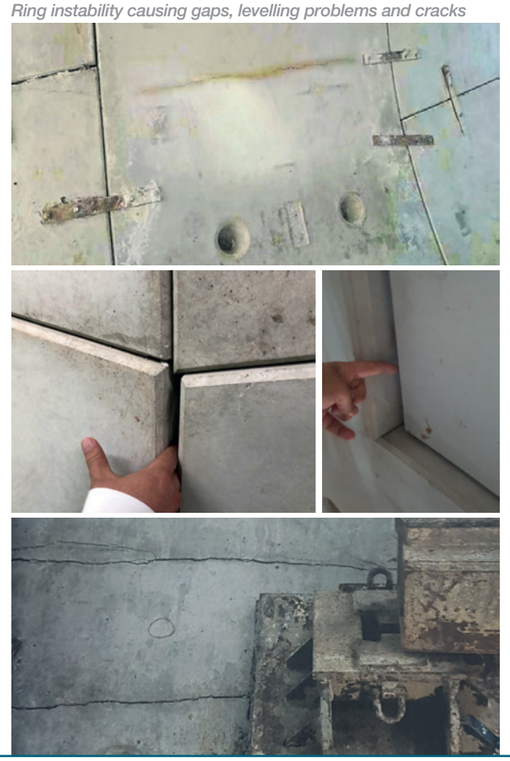
"The bolted and gasketed GFRP+MSF reinforced segmental lining comprised five segments and a key in each 1.5m wide x 300mm thick x 6m o.d. ring. The longitudinal cracks in the GFRP+MSF segments began to appear while passing through the NATM section and also once the TBM began excavating the ground and applying high excavation forward thrust to the segmental lining.

"Approximately 55 rings of GFRP+MSF reinforced segments were placed in the first tube, with about five of them in TBM excavated ground, which is safer than in the NATM section for segment loads. After segment cracks occurred in both the NATM and the ground excavation sections, the segment design, and production, was changed from GFRP+MSF reinforcement to traditional heavy steel rebar cage reinforcement.

"When the TBM in the second tube launched in September 2019, the same method was used for the false tunnel and the 100m long NATM starter tunnel, with segments of traditional heavy steel rebar cage reinforcement of 1,100kg/ring. Of the 10 rings of these steel rebar cage segmental rings installed for the second tube, wide cracks, gaps and alignment problems were once again encountered. The works progressed with the traditionally reinforced segments and the job site was closed to any further study pending the results of an official investigation.

"All concerns and considerations for the possible causes of the GFRP+MSF hybrid, and traditional steel rebar cage reinforced segmental lining as built, were conveyed to the contractor by the consultants and other participants of the project. With cracks appearing in both the rings of GFRP+MSF and traditional steel rebar reinforced segments, it is evident that the issue is concerned with the instability of the ring build and not a fault of the reinforcement." ■

Ring instability causing gaps, levelling problems and cracks



Correct TBM launch in a NATM starter tunnel

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Promoting macro synthetic fibre reinforcement

MSFA News Release

With the growing acceptance of macro synthetic fibre (MSF) as a structural concrete reinforcement, companies and individuals working in this specialised field have come together to form an association to promote and continue the development and application of the product. The Macro Synthetic Fibre Association promotes the advantages of MSF and invites membership of the Association.

- Macro synthetic fibres were first developed by 3M in the USA in 1989. The technology has spread widely since and includes shotcrete and tunnel linings.
- Hagihara Industries in Japan developed the embossed MSF in the late 1990s. The high tenacity and the new bonding system set new milestones in performance levels.
- Australia led the way in the use of MSF reinforced shotcrete (MSFRS) for ground stabilisation in mines, today with almost 100% uptake.
- Norway, as a leader in the development of wet shotcrete in the 1990s, led the way of MSF into civil tunnel applications.
- More recently, numerous MSF reinforced concrete and shotcrete tunnel lining projects have been completed internationally.

Factors driving the use of MSF reinforcement in sprayed concrete have included:

- Economics: Macro synthetic fibre reinforced shotcrete (MSFRS) costs less compared to steel reinforcement.
- Effectiveness: MSFRS works better for stabilizing deforming ground and is more durable.

Macro synthetic fibre reinforcement

- Ductility: MSFRS exhibits higher toughness than alternative forms of concrete reinforcement.
- Handling: Synthetic fibres are light and readily transported and handled.
- Durability: Water percolation in conjunction with chloride- and sulphate-containing ground has proven destructive to steel reinforcement in underground environments. Experience in mining has shown that small cracks enable percolating water to bring oxygen and salt ions directly to the surface of the reinforcement leading to corrosion and loss of structural competence. Numerous mines have switched to macro-synthetics based on the durability of polymer reinforcement.[1]
- Long-term performance: MSFRS using high quality synthetic fibre does not show post-crack performance loss with age. In contrast, steel alternatives can exhibit loss of residual performance due to post-hardening effects of the matrix, also known as embrittlement. Neither corrosion nor embrittlement occur in MSFRC, so the long-term performance remains close to or better than the 28-day measured performance for cracks up to 0.30mm in aggressive environments.

Table 1. Codes for steel and macro synthetic fibre reinforcement concrete

Regulation of the fibre product	EN 14889–2:2006 Fibres for Concrete, Part 2: Polymer fibres Harmonised European Standard covering definitions, specifications and conformity of macro synthetic fibre (MSF). Most quality MSF in the market carry CE certification System I for structural applications
	ASTM C1116/C1116M–10a Standard Specification for Fiber-Reinforced Concrete (FRC), The US standard for FRC
General design of concrete structures	Guidelines for the design, construction and production control of FRC structures. CNR DT-204, National Research Council, Italy, 2006
	fib Model Code 2010 for Concrete Structures, International Federation for Structural Concrete, 2012
	ACI 544.4R-18 Guide to Design with Fiber-Reinforced Concrete, American Concrete Institute, 2018
Fibre reinforced shotcrete	ACI 506.1R-08 Guide to Fiber-Reinforced Shotcrete, American Concrete Institute, 2008
	ACI 506.5R-09 Guide for Specifying Underground Shotcrete, American Concrete Institute, 2009
	Shotcreting in Australia - Recommended Practice, 2nd Edition, September 2010 Prepared by the Australian Shotcrete Society, published by the Concrete Institute of Australia
Precast segmental tunnel linings	Design of concrete segmental tunnel linings – Code of practice PAS 8810, April 2016, Publicly Available Specification by HS2, British Tunnelling Society and BSI by the British Standards Institution
	Specification for Tunnelling, 3rd edition, March 2010 Published by the British Tunnelling Society and the Institution of Civil Engineers
	Guidance for Precast Fibre Reinforced Concrete Segments – Vol. 1 Design Aspects ITAtech report No 7, April 2016. ITA-AITES
	Precast tunnel segments in fibre-reinforced concrete, State-of-the-art report intended to complement the fib Model Code 2010 fib bulletin 83, International Federation for Structural Concrete, 2017

Adoption of MSF in civil projects

The civil tunnelling industry is steadily moving in the direction of synthetic reinforcement. MSFRS has been used for temporary linings of numerous tunnels, but not until recently for permanent lining. MSF has been used also in linings that are sensitive to deflections and ground subsidence without adverse outcomes. An example of such an application is for the North Strathfield underpass project near Sydney, Australia.[3]

As more tunnels are being designed and constructed using this type of fibre reinforcement, there are no reported projects in which excessive convergence or ground subsidence could be attributed to creep of macro-synthetic FRS. These factors are controlled by tunnel design and excavation sequences, not by composition of the fibre.

Development of the MSF Association

In order to create a united voice for the industry, leading manufacturers of macro synthetic fibre have established the Association. A first meeting of the Association was held at the WTC World Tunnel Congress in 2016 in San Francisco, and the Association was formed as a non-profit organisation at a base in Switzerland in October 2017. The first General Meeting of the Association was at the WTC 2018 in Dubai. The MSFA today comprises ten member companies.

The role of the MSFA is to provide confidence and support to users by education and training, as well as resolving the various technical issues that are still seen as barriers to entry into the market for this product. Today, numerous copies of the initially engineered quality fibre types have emerged from producers in numerous countries where care must be taken with the quality and performance claims. In this regard, important steps have been taken towards standardisation, not only with regards to the general regulation of the fibre product, but also in the structural design and application in practice (Table 1).

Full membership of the Association is open to companies or individuals engaged in development, manufacturing, sales or use of macro synthetic fibres, with the common interest of growing the responsible use of high quality MSF.

Industry Feedback

From: Des Vlietstra, Technical Consultant, Barchip Inc.

In response to the suggestion that macro synthetic fibre is "attracting some environmental concerns", it comes down to responsible behaviour by humans. Macro synthetic fibre used correctly in concrete will significantly reduce the carbon which is produced by using the equivalent in steel fibre. As such, this is not an environmental concern, it is a step in the right direction. It is humans that dispose of macro synthetic fibre incorrectly or irresponsibly that pose an environmental concern.

From: Denis Crehan

In an industry where CO_2 savings are hard to achieve, a 70-80% reduction in CO_2 emissions is achievable using macro synthetic fibre reinforcing compared to steel mesh or steel fibre. The Intergovernmental Panel on Climate Change (IPCC) report of 2018 suggests that keeping the rise in global temperatures to below the 1.5°C target would require a decline in global emissions of CO_2 by 45% from 2010 levels by 2030. ■

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Main line TBMs launch on Brenner Base Mules Lot

Patrick Reynolds and Roland Herr for *TunnelTalk*

Large TBM excavation of the main running tunnels for the 55km long Brenner Base Tunnel between Austria and Italy began, with launch of two 10.65m diameter Herrenknecht double shield TBMs on the Mules Lot after establishment of works by extensive drill+blast. A third machine working on contract is excavating the exploratory tunnel.

Contractor Astaldi/Ghella JV has been advancing the 20km of the Mules Lot since award of contract in late 2016.

Working from the previously excavated Mules adit, the JV began main tunnel excavation using drill+blast in both directions and is excavating southward to reach the boundary with the adjacent Isarco Lot. In the northward direction it has advanced to the Trens multifunctional emergency stop complex. It is from here that the two large TBMs are launched to continue north to the border with Austria and interface with the Pfons-Brenner Lot (Fig 1). Excavation of the south drives is expected to finish by mid-2020, according to client delivery partner BBT-SE.

The 6.82m diameter exploratory tunnel TBM was launched in May 2018, some 600m north of the Mules adit, and the machine is due to reach the adjacent contract interface in 2021. Its progress, combined with that of the earlier drill+blast works, has achieved a total of nearly 5km of the 14.8km exploratory tunnel in the Mules Lot.

The main tunnel TBMs, launched in April and May 2019, are expected to reach the end of their drives by 2022 carrying on from almost 7km of main tunnel drill+blast excavation on the lot. The TBMs are erecting a 450mm thick segmental lining in 1.75m long rings as they progress through mainly calcareous schists and gneiss geology beneath the mountainous overburden of between 590m and 1,750m.

There is one large lot yet to be awarded on the mega baseline project. This is the Pfons-Sillschlucht Lot at the northern end of the route in Austria. The Lot involves a total 7km of parallel main running tunnel excavation, the parallel exploratory tunnel from the existing Ahrental Adit, and completion of the section to reach Innsbruck.

Other works underway on the major rail baseline project are on the Pfons-Brenner Lot, the Tulfes-Pfons Lot, and the Isarco Underpass Lot (Fig 2).

The Pfons-Brenner Lot was awarded in late 2017 to the Porr-Hinteregger-Condotte-Itinera JV and calls for construction of a total 46km of excavation for the main running tunnels and the exploratory tunnel. Excavations will involve both TBM and drill+blast excavation. The package also includes excavation of the St Jodok emergency stop complex, comprising enlarged main running tunnels plus cross passages at 90m intervals. The lot also includes a total of 6.2km of safety and logistics tunnels.

Construction on the Lot began in 2018 and BBT-SE expects the works to last 74 months. Early progress has seen about 500m of the exploratory service tunnel and almost 460m of the safety and logistics tunnels excavated.

The Tulfes-Pfons Lot and the Isarco Underpass Lot are both being advanced by the Salini-Impregilo/Strabag JV.

Excavation on the Tulfes-Pfons Lot at the Austrian end of the route, which included a number of tunnels and sites in a complex layout, was completed in July 2019. The lot includes 38km of tunnels, including almost 6km of drill+blast excavation for the main running tunnels, and 15km of the exploratory tunnel using a 7.93m diameter Herrenknecht open gripper TBM. Other drill+blast excavations in the Lot from the Ahrental Adit include a 9.7km long emergency tunnel,

Mules Lot TBMs underway

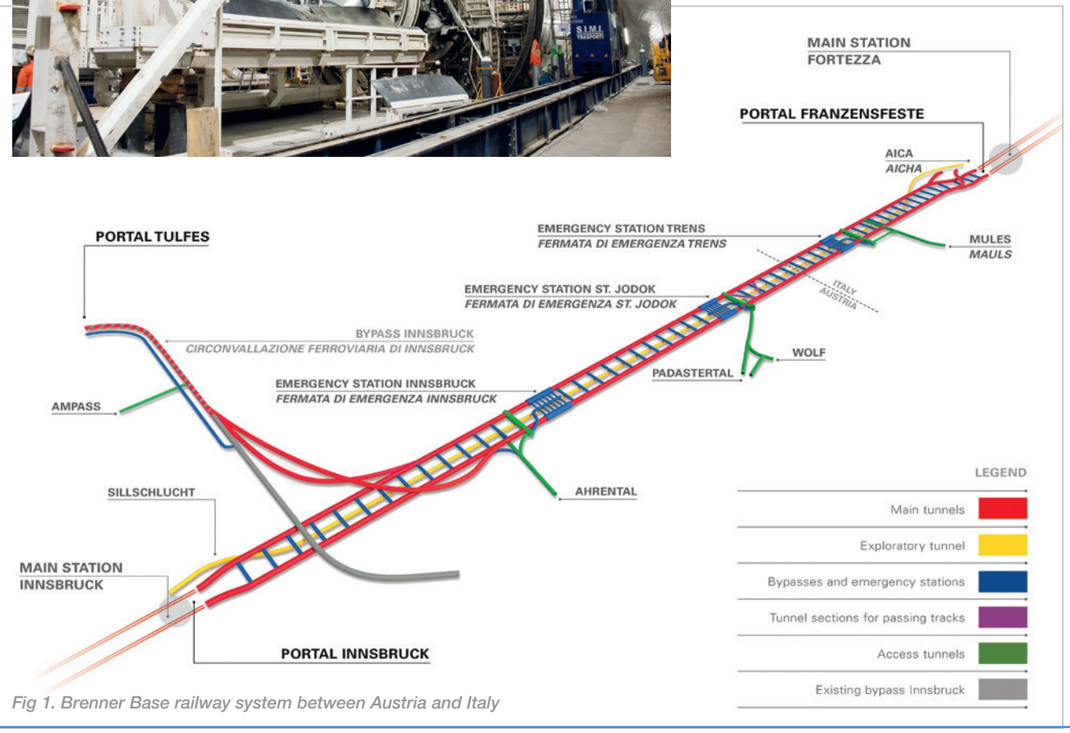

Fig 1. Brenner Base railway system between Austria and Italy

Drill+blast established start of the Mules Lot

6.9km of connecting tunnels, and a 1.8km long emergency stop tunnel.

On the Isarco Lot, construction of the 2.25km of twin running tunnels is complex with both soft ground conditions calling for ground freezing and jet grouting under the Isarco River, and drill+blast once into the hillside. Construction began in 2014 and is scheduled for completion by late 2022.

Early works also included excavation of the Wolf Adit on the Pfons-Brenner main line Lot. The Wolf 2 Lot also excavated about 1.2km of the exploratory tunnel. A further 9km of exploratory tunnel will be excavated by drill+blast within the Pfons-Brenner Lot.

Exploratory tunnel debate

A special feature of the Brenner Base Tunnel is the 5m diameter exploratory tunnel that runs between, and 12m below, the two main tubes. The cost of the exploratory tunnel is about 12% of the total costs of the project, an issue that has been questioned.

However, for Konrad Bergmeister, former Joint-CEO of BBT SE for Austria, there are four main advantages to having the tunnel, the primary one being the geological, hydrological and geotechnical exploration of the rock mass encountered. "As we learned from the construction of other baseline railway tunnels including the Lötschberg and Gotthard in Switzerland, only some rudimentary estimations of the possible rock mass behaviour can be achieved from the different investigations carried out in the preparation phase. With an exploratory tunnel we get a much better investigation of the rock mass and its behaviour."

A second advantage is the water drainage system. The exploratory tunnel creates a completely independent system that will be used during the construction and the operational phase. This allows periodical cleaning of the drainage system, with no need to stop train services during maintenance.

Thirdly, the exploratory tunnel allows access to geologically difficult zones of the main tunnels in advance of their excavation. In the case of difficult geo-hydrological zones, it is possible to insert ground treatment directly from the exploratory tunnel in advance of main tunnel excavations, preventing dangerous incidents and expensive interruptions. It is also possible to access the alignment of the main tunnels via shafts or ramps to bypass difficult geotechnical stretches of the main tunnels and assist main tunnel excavation from the exploratory tunnel.

A fourth advantage involves rail equipment. Long railway tunnels face the problem that all rail equipment has to be placed in the connection tunnels or directly in the main tunnels, meaning that one main tunnel has to be closed during inspection or maintenance. "In our case, we are now studying what equipment can be placed in the exploratory tunnel. Then operation in the main tunnels will be completely independent of maintenance of those systems," added Bergmeister.

"The additional construction cost of the exploratory tunnel results in savings in terms of reduced risks and costs for the main tunnel, and an optimised life cycle management during operation," concluded Bergmeister.

Excavation of the completed Tulfes-Pfons Lot included construction of a 15km reach of exploratory tunnel between the Ahrental junction point and the town of Pfons (Fig 1). Several fault zones were encountered over the first 13km. The largest overbreak showed a cavity volume of about 5,500m³ and a cavity height of 18m. Pressure on the TBM grippers in fault zones exceeded 400bar, and water ingress of more than 70 litres/sec was encountered.

The use of the open gripper Herrenknecht TBM for the 15km exploration proved wise, and the methods developed to handle the unexpected overbreaks proved successful. In spite of the significantly increased costs due to geotechnical reasons, the originally agreed construction schedule was exceeded by about 10%.

Excavation of the main tunnels of the remaining lots of the project will all benefit from the findings of the pre-excavated exploratory tunnel. All excavation is expected to end by early 2025. ■

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New CEOs for Brenner project

Joint CEO Chief Executive Officers, Konrad Bergmeister and Raffaele Zurlo left their positions with the Brenner Base Tunnel (BBT) project delivery organisation in September 2019. The decision brings an end to the turbulent relationship between the two men, which was a key factor in the Board's move to replace them. Prof Bergmeister of Austria had been CEO of BBT since 2006. Zurlo of Italy took up his position in 2010.

New CEOs Gilberto Cardola of Italy (left) and Martin Gradnitzer of Austria (right)

Martin Gradnitzer of Austria and Gilberto Cardola of Italy will take over as joint CEOs of the bi-national mega-project. Gradnitzer has been Project Manager at ÖBB, the Austrian railway company, working on the Lower Inn Valley access route to the BBT in Austria. Cardola was responsible for management of national activities at Italferr, a company of the Italian state railway company.

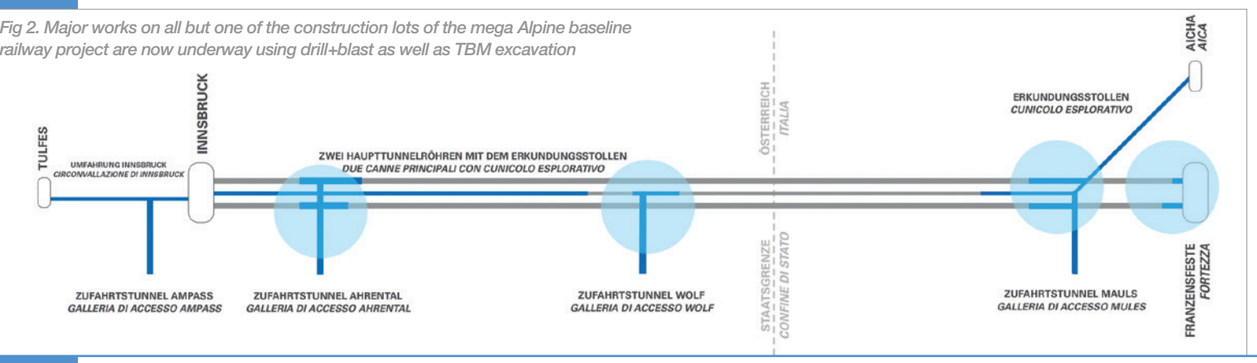
Bergmeister had offered to resign despite his contract being extended in 2018. Zurlo had also received a three-year extension to his contract earlier in 2019.

The relationship between the two men was complicated by the dual system of decision-making at BBT, which straddles both Austrian and Italian jurisdictions. The problems came to a head when the project moved to construction and different regulations and laws in the two countries were applied to the tender invitation and procurement processes. The project was also under pressure from the European Union, which wanted to reduce its financial support.

Commercial construction invoicing will now be separated and executed under the national laws of Austria and Italy.

Joint CEOs Gradnitzer and Cardola now take up the responsibilities of taking the project through to completion. All excavation is scheduled to be complete by the end of 2023 on the Italian side and a year later, at the end of 2024 or early 2025 on the Austrian side, with train services expected to begin in 2028. ■

Fig 2. Major works on all but one of the construction lots of the mega Alpine baseline railway project are now underway using drill+blast as well as TBM excavation



Lötschberg plans full rail line buildout

Patrick Reynolds for *TunnelTalk*

The BLS AG (Bern–Lötschberg–Simplon) rail company in Switzerland is to submit plans to the Swiss Federal Office of Transport to fully complete both tubes of the Lötschberg Base Tunnel. Opened 12 years ago with a single operation tube, the line has quickly become a bottleneck to growing rail freight across the Alps. To become a twin track facility, about 7km of the west tube remains to be excavated, the excavated parts of the west tunnel are to be fitted out for operation, and a new crossover is to be excavated and equipped (Fig 1).

BLS Project Manager for Lötschberg, Stefan Irngartinger, told *TunnelTalk* that the rail company will carry out detailed design and procurement planning towards receiving approval for the works by mid-2020, a call for tenders in 2021, and for construction to start in 2021/2022 and be completed by end of 2028.

The 34.6km long Lötschberg Base Tunnel opened in mid-2007 and was designed and excavated as a twin tube facility with linking cross passages, but only the east tunnel was fully completed and operational. Much of the west tube was excavated but not fully equipped. As a result, the Lötschberg tunnel runs about 20km, or the majority of its length, in a bottleneck single tube format that restricts capacity.

The plan was to fully complete the Lötschberg link once funding was available. Funding to fully complete the Alpine strategic rail link is coming from the Swiss Government as part of its large Strategic Expansion Programme of rail investment for the country. The budget for the completion of Lötschberg is estimated at CHF 920 million (USD$922 million) in 2015 prices and has a margin for change allowance of +/- 25%.

Construction for Lötschberg was mainly by drill+blast. The geology exhibited a north-south split with flysch, marly limestone, slate and sandstone at the north end, granite in the middle and schists, gneiss, amphibolites and sediments in the south. Excavation progressed from the north and south portals and three intermediate adits with 80% completed by drill+blast on headings of 65m² to 78m². The balance, at the south end, was completed by 9.43m diameter TBMs.

Daily, the base tunnel, despite the bottleneck constraints, accommodates up to 60 freight trains plus about 50 passenger trains.

In 2014, the electorate voted to fund the completion of Lötschberg. Irngartinger told *TunnelTalk*: "The west tunnel will be both a construction site and an emergency exit for the operating east tunnel."

The west tunnel was excavated but only structurally completed and equipped along its first 14km at the south end. The remaining part of the tunnel has a primary lining and will require installation of the invert and final lining as well as fit-out of tracks and M&E equipment.

Maintenance access and evacuation routes from the operating east tunnel for the 7km unexcavated part of the west tunnel are provided through the 9.5km Kandertal exploratory tunnel running on the other side of the east tube. The exploratory tunnel was excavated by a 5m diameter TBM in the mid-1990s.

The Lötschberg rail corridor also includes the 2.6km long twin tube Engstlige tunnel built by cut-and-cover. With only its east tunnel equipped for operation, current planning is to include track and M&E equipment through the west tunnel.

The excavation method for the majority of the tunnelling will probably be drill+blast,

Fig 1. Operating tunnel and completion works

said Irngartinger. The works will involve excavation of new tunnel sections and caverns close to the operating east tunnel, analysing the stresses and deformations of the inner lining in the east tunnel and comparing the data with those of the unfinished west tunnel, and matching infrastructure across the tunnels, noting that some components will be nearing their lifetime usefulness. Everything will have to be completed while train services continue. The construction and excavations adjacent to the east tunnel involve backfilling an existing crossover tunnel and creating a new, longer, crossover capable of carrying faster trains. ■

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Poland progresses new TBM road link

Jaroslaw Adamowski for *TunnelTalk*

A new TBM road tunnel for the island city of Świnoujście is to be completed under a contract worth €185.3 million by a consortium led by Porr of Austria. The tunnel, under the Swine River, will connect two of the city's largest islands. Together with Porr, the consortium comprises Turkey-based Gülermak, and Polish company Energopol Szczecin.

The project is about 3.2km long with a 1.44km slurry TBM drive under the river. A 13.5m TBM diameter is needed to excavate a single tube tunnel to house two 3.5m wide traffic lanes for bi-directional traffic. Evacuation niches fitted with staircases will provide access to the fresh air channel located under the road deck for evacuation during emergencies. The emergency niches will be situated on one side of the tunnel and will be broken out of the segmentally lined tunnel and excavated under ground freezing support.

Initially, the project was to be completed by a consortium of Astaldi and Ghella of Italy, but the two companies

Island city of *Świnoujście*

decided to pull out of the contract because the costs of labour and materials increased significantly and caused an increase in the costs of the necessary construction work.

Construction of the project is expected to take 48 months, allowing the investment to be completed in 2022.

Porr has also signed a contract for the design and construction of section 3 of the S3 express road project in the southwest of Poland on which two tunnels, of 2.3km and 320m long, are to be built.

The project in Świnoujście is the second TBM highway tunnel under a river in Poland. The first is the 12.5m diameter x 1.3km long highway link under the Vistula River in Gdansk on the Polish Baltic Sea shore, which opened to traffic in 2016.

A significant portion of the Swine Tunnel investment is secured with funding from the European Union.

Świnoujście is located on 44 islands, only three of which are inhabited. Currently, transportation between the islands is by ferry with outdated vessels, according to the municipality. Long lines of passengers, as well as times when Świnoujście is cut off from the rest of the country during unfavourable weather will be solved by building a permanent connection. ■

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Fast paced refurbished Mixshield in The Hague

Herrenknecht News Release

A refurbished 11.34m diameter Mixshield TBM from Herreknecht took just one year to successfully excavate the twin tubes of the 1.6km Victory Boogie Woogie road tunnel as part of the 4km Rotterdamsebaan project to connect the Ypenburg interchange with the ring road of The Hague in the Netherlands.

To overcome challenging ground conditions, due to more than half of the country being below sea level, project partners were able to draw on previous experiences. Between 2013 and 2015, the same Mixshield excavated the Sluiskil Tunnel in the Netherlands.

After refurbishment at the Herrenknecht plant in Kehl, the TBM started work on the first of the two 10.15m i.d. tunnels for the Rotterdamsebaan road link in January 2018 and broke through in July 2018. After disassembly, return transport to the working portal and reassembly, the TBM and its site crew excavated the second tube between September 2018 and January 2019.

At more than 1,600 tonnes and about 80m long, the reused TBM achieved advance rates of up to 16.9m/day for the Combinatie Rotterdamsebaan JV comprising Wayss & Freytag, BAM Infra and VolkerWessels. The JV is responsible for the design, preparation and realisation of the project and will maintain the 4km-long link road for a period of 15 years.

The TBM, originally designed to excavate the heterogeneous sand, silt and clogging-prone clay geological conditions of the Sluiskil Tunnel, has an open spoke cutting wheel with direct material transport from the cutting wheel centre and an optimally adapted slurry circuit.

The cutterhead was painted in yellow, red and blue, and due to the low abrasiveness of the soil, the colours were still clearly visible after final breakthrough.

After commissioning in July 2020, the new road link will significantly reduce congestion on the Utrechtsebaan and other traffic routes in the area. ■

References

- Innovation gets Amsterdam Metro on track – *TunnelTalk*, July 2014

From left: Transport through The Hague back to the starting point via inner-city canals; Final breakthrough in January 2019

Progress for Milan-Genoa high speed rail link

Salini Impregilo News Release

Excavation of the underground section of Terzo Valico dei Giovi, the high speed rail link between Genoa and Milan in Italy, progressed to more than 40% complete during 2019 according to COCIV, the construction JV led by Salini Impregilo.

About 37km of the 53km long Terzo Valico Milan-Genoa is aligned underground. It will cross 14 municipalities in the provinces of Genoa and Alessandria as well as the regions of Liguria and Piedmont. Work has also been completed on the access adits: Polcevera, Cravasco, Castagnola and Val Lemme, and related junction chambers with the main tunnel route. Excavation is at full capacity along the main line and the connection to the Genoa rail line.

The project will support the flow of people and merchandise between northern Italy and the rest of Europe. It will create a 50 minute connection between Genoa and Milan versus the current one hour and 39 minutes.

Terzo Valico dei Giovi is a priority project for the European Union as part of the Trans-European Transport Network to develop a network across the Rhine-Alpine rail corridor linking Genoa with Rotterdam, or the Mediterranean with the North Sea. ■

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From left: Construction at Libarna in Alessandria; The twin tube Valico Tunnel in the south

Terratec News Release

EPBMs on Istanbul Metro expansion

Among nine Terratec EPBMs working on the Istanbul Metro system expansion are two ordered by the Halkali-Yeni Havalimani Metro JV of Cengiz Insaat, Kalyon and Kolin to work on the Halkali-Istanbul New Airport metro line. To suit the mixed geology of Istanbul, which includes reaches in sandstone, siltstone, limestone and volcanic rock, the 6.56m TBMs have versatile mixed-face dome-style cutterheads with an opening ratio of about 35%. They also feature VFD electric cutterhead drives, tungsten carbide soft ground cutting tools that are interchangeable with 17in roller disc cutters, high torque screw conveyors and active articulation systems.

The Halkali-New Airport metro line will comprise a 31km long line with six new stations to form the western-leg of the new M11 Line that runs from the recently opened third international airport on the European side of Istanbul, southwards to Halkali, which is also the terminus of the Marmaray railway under the Bosphorus.

It is one of a number of new metro lines currently being built in the city that will increase the current 145km metro network in Istanbul to more than 480km. Members of the JV were impressed with performance of previous Terratec machines on the metro contracts and decided to employ a further four new machines on the Halkali-New Airport link. ■

Successful EPBM factory acceptance

Istanbul Metro progress so far

References

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XRE TBM conquers toughest drive in Turkey

Desiree Willis, Technical Writer, The Robbins Company

Excavation of the longest water tunnel in Turkey was completed by a 5.56m diameter Robbins XRE Crossover TBM that overcame 48 fault zones and water ingress pressures of up to 26 bar.

Contractor JV Kolin/Limak started excavation of the 31.6km long Gerede water project using three double shield TBMs supplied by another manufacturer. When these encountered incredibly difficult geology and massive inrushes of mud and water they came to a standstill.

The 9km long final leg of the tunnel through difficult sandstone agglomerate, limestone and tuff, is widely considered to be the most challenging ever excavated by TBM in Turkey. The Kolin/Limak JV contacted engineers at The Robbins Company, who suggested a Crossover dual-mode type TBM for the remaining section of tunnel. "The TBM was equipped with increased thrust, two-speed gearboxes, and a modular screw conveyor. Together they provide versatility to drive through frequently changing ground conditions," said Barıs Duman, Project Manager for the Kolin-Limak JV.

The specialized machine was designed to hold water pressure of up to 20 bar in a static sate - a failsafe that none of the initial double shield TBMs had been equipped with. It was fitted with a convertible cutterhead designed for ease of conversion between hard rock and EPB modes, and with cutter housings that could be fitted with either disc cutters or tungsten carbide tooling. The Gerede TBM was also equipped with the torque-shift system multi-speed gearing, allowing the machine to function as either an EPB or a hard rock TBM. This function is activated by adding another gear reduction with heavy duty pinions and bull gears to accommodate high torque at low speed, allowing the machine to bore through fault zones and soft ground without becoming stuck.

The TBM was delivered to Turkey and assembled in 2016 after crews excavated a bypass tunnel to one side of one of the stuck double shield TBMs. An underground assembly chamber allowed the machine to be built in the tunnel using OFTA (onsite first time assembly). "Getting components through the existing tunnel was a challenging process," said Glen Maynard, Robbins Field Service Site Manager. "The assembly chamber was 7km from the portal and water inflows of up to 600 l/sec made it difficult."

Despite the challenges, within the first 50m, the machine, in EPB mode, had successfully passed through the section that had buried the original TBM. Water pressure was lowered by drain holes drilled through rear shield probe drill ports, equipped with normally-closed ball valves. Probe drilling was undertaken on a routine basis to get through the ground conditions. "Tunnel excavation achieved a best day of 29.4m, a best week of 134.6m and a best month of 484m," said Duman.

"We had many challenging areas with high volume water ingress under high pressures of up to 26 bar, along with flowing alluvial material in 48 fault zones," continued Duman. "Ground pressure on the shield body caused squeezing conditions in clay. We were able to quickly pass through by keeping the TBM advance rate, cutterhead rev/min and screw conveyor rotation speeds at the ideal level."

The tunnel is needed urgently to convey water from the Gerede River to the Çamlidere Dam, which provides potable water for the Ankara city water system. ■

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Journey through completed reaches to the XRE TBM assembly chamber

Assembly of the TBM more than 7km into the tunnel drive

Objections filed as Fehmarn prepares for construction

Patrick Reynolds for *TunnelTalk*

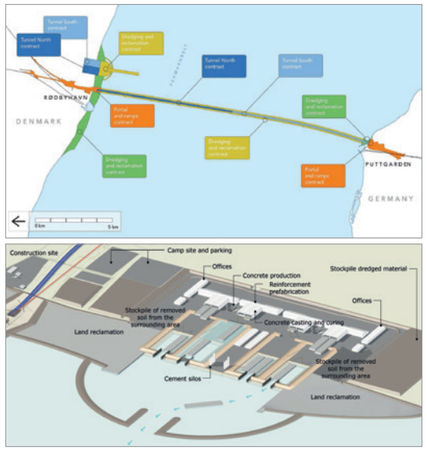
Formal legal objections have been lodged in Germany against the 17.6km long Fehmarnbaelt road and rail sea link between Denmark and Germany following environmental approval for the project by the German State of Schleswig-Holstein in February 2019. The seven legal complaints, to be heard by the Federal Administrative Court of Germany, were filed by:

- three ferry companies;
- two German environmental groups;
- two municipalities; and
- a local landowner.

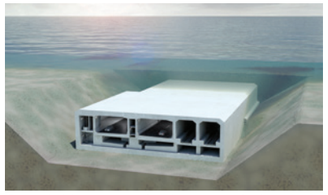
Femern A/S anticipates that legal challenges might take up to two years to resolve.

In anticipation of objections, Femern A/S reviewed the potential impacts and concluded the timeline should not be impacted and extra costs would be covered within the existing construction budget.

With Denmark leading the mega



From top: Contract packages of Fehmarn fixed link; Construction to start at Rødbyhavn casting factory



Special immersed tube tunnel element

project, Femern A/S was granted permission from the Danish Government to start some of the main construction works in Denmark in 2019.

Jens Villemoes, Media Spokesman for Femern A/S told *TunnelTalk* that work on the drydock harbour at Rødbyhavn was to begin in Autumn 2019 and take two years to complete. Early main works in Denmark will also include construction of the immersed tube element precasting factory and necessary near-shore dredging and reclamation.

Villemoes said that the early works covered in the construction budget will be advanced by the contractors of the large construction contracts awarded conditionally to:

- a Vinci-led consortium for the tunnel, portal and ramps and
- a Boskalis-led group for the dredging and reclamation works.

Talks with the contractors are still ongoing, he said, though preparatory works at the Danish construction site are continuing as planned.

The overall cost of the Fehmarn toll-link project is budgeted at DKr 52.6 billion, about USD$8 billion, in 2015 prices, of which DKr 7.3 billion is reserves. The Danish Government has provided State guarantees on the loans.

The early works will trigger the release of a significant portion of approved European Union project funding, said Villemoes. The funding is applicable for up to 40% of railway only related costs that account for about one-third of the overall road-rail project. About 20% of the cost of the early construction works are eligible to draw funds from the European Union subsidy.

"Now we embark on a new chapter of the Fehmarnbelt Fixed Link project," Femern A/S CEO, Claus F Baunkjær, told *TunnelTalk*. "The implementation of a number of major construction activities will make best use of the time and ensure progress on the project. This is a very important step."

The immersed tube element factory is being constructed in stages with the first production lines expected to be operational in Autumn 2021. Casting is expected to begin in early 2022. Once fully operational, the factory should be capable of casting a tunnel element every two weeks. A total of 89 elements are to be cast – 79 standard and 10 special elements which are shorter and deeper to include a basement level for technical equipment.

Follow-on main construction activities would include all offshore dredging, all concrete casting, the float-out and placement of the elements, and all construction work at the portal ramps near Puttgarden in German. Their timing will depend on the status of the German court case, explained Villemoes.

Villemoes also explained that an expedited permit was granted to allow some preparatory works at Puttgarden in Germany while the court case proceeds.

"Complaints were expected," said Villemoes. "We are well prepared for a coming court case and do not expect to adjust our time plan." The targeted opening of the sea link remains 2028. ■

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Stockholm cable connection

Patrick Reynolds for *TunnelTalk*

Excavation of a 14km cable tunnel at up to 100m below Stockholm is awarded by the Swedish national grid company Svenska Kraftnat to the Hochtief/Implenia JV, valued at about €90 million (USD$102 million). Hochtief has the lead technical role in the 50:50 JV, which will use a gripper TBM to bore the 5m diameter Anneberg-Skanstull cable tunnel (Fig 1).

The TBM will bore through typical Scandinavian hard rock comprising metagreywacke, granite and gneiss. The tunnel is designed to be largely unlined, except for some spot bolting and shotcreting, explained JV Project Director, Christian Zimmermann of Hochtief. With the vertical alignment below groundwater level, the contract will require significant pre-excavation grouting ahead of the TBM.

The TBM will be stopped every 15m to complete the rounds of systematic grouting, said Zimmermann. The main challenge, he said, will be to achieve maximum utilisation of the TBM within available working hours to limit noise and vibration while beneath the city.

Contract works include construction of six ventilation shafts with associated service tunnels to be excavated by drill+blast. Four 4m-diameter shafts will be excavated by raise boring and the other two, about 40m^2 in cross-section, will be drill+blast shaft sinking operations.

The cable tunnel is due to be completed in 2024 and will form a key part of the Svenska Kraftnat City Link project to improve electricity supplies in the capital. ■

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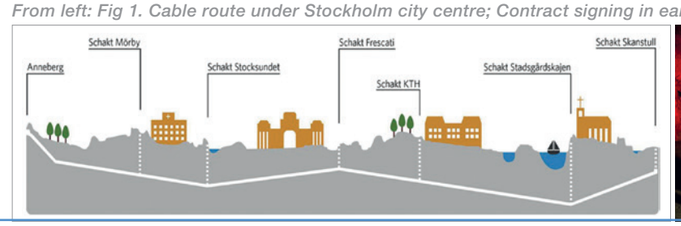
- Implenia transport tunnel works in Stockholm – *TunnelTalk*, April 2017

From left: Fig 1. Cable route under Stockholm city centre; Contract signing in early 2019



Chinese onboard for TBM-bored Helsinki-Tallinn link

Jonathan Rowland, *TunnelTalk*

Development of the proposed FinEst Helsinki-Tallinn rail link has entered the environmental impact assessments (EIA) stage and engineering companies ÅF Pöyry and AINS are progressing design work. They are joined by China Rail International Group (CRIG), which has signed a memorandum of understanding for construction with project developer FinEst Bay Development; TouchStone Capital Partners, which is providing funding; and Turkish contractor GAMA Holding.

The project includes twin TBM 100km long TBM rail tunnels for dedicated passenger and freight routes between the airports of the Finnish capital Helsinki and Estonian capital Tallinn as well as two artificial islands. High-speed rail services would link the two cities in 20 - 25 minutes, creating a metropolitan zone of more than 2 million people.

In Finland, the EIA process began some time ago and has completed the public comment phase.

On the Estonian side, the EIA process is awaiting key decisions by the Estonian Government in order to proceed. "We are responding to requests for further information," said Kustaa Valtonen, a cofounder and co-owner of FinEst Bay Area Development. "Hopefully, when they have received this information, they will make their decisions quickly and we can proceed."

Completion of the EIA process will determine which route will be developed. Three options are under investigation on the Finnish side and four on the Estonian side (Fig 1).

"Engineering and technical design has been started by Pöyry and AINS," said Valtonen. "The work will now be accelerated with the addition of CRIG to the team."

Construction of the 100km route will be by TBMs of 17.4m diameter, confirmed Valtonen. "This is not an easy task, but it is achievable based on the geology between Finland and Estonia. The bedrock is granite and ideal to bore through." The longest drive will be about 25-30km between two artificial islands of the project. At the deepest point, the tunnels will be up to 250m below sea level.

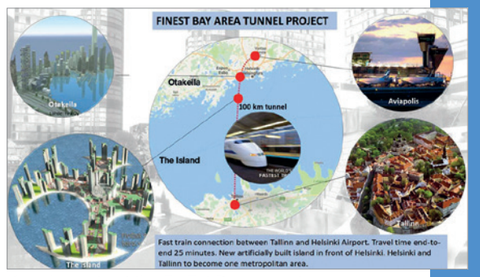
"The project is already looking at potential TBM suppliers including Herrenknecht, Robbins, and Hitachi, as well as a couple of Chinese alternatives," said Valtonen. "The decision will be taken in the first half of 2020, when we begin the procurement process." TBM installation would then begin at some point in 2021 with work expected to last about 2.5 years. This would fit with the ambitious projected opening of the route in late 2024.

The two artificial islands are primarily needed for ventilation and emergency exits. Excavated rock will be used to create the islands, reducing the impact along the rest of the route. The larger of the two islands, off the coast of Finland, will include commercial and residential spaces.

The project budget is set at €15 billion. Excavation will cost about €12.5 billion. A third of the funding will be provided by TouchStone Capital Partners, which has many Chinese state-owned enterprises as investors. Neither CRIG nor its parent company, China Rail Group (CREC), are investing in the project, said Vantonen, and Chinese ownership of the project will be limited to less than 50% to allay security fears, particularly on the Estonian side.

Additional investors are being sought in Europe. "We would like to bring in local Finnish and Nordic funding partners, as well as from Europe, just to keep a good balance of funding."

It is estimated that project investment alone will result in a 1.1%/year increase in Finnish GDP and a 2.5%/year increase in Estonian GDP between 2021 and 2025. The long-term economic benefits are expected to be far higher. ■



Key elements of the FinEst Bay project

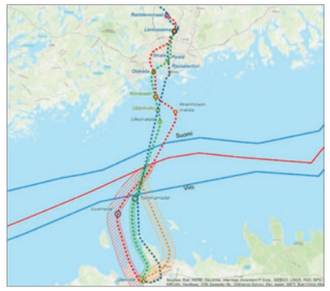


Fig 1. Potential Helsinki-Tallinn routes

References

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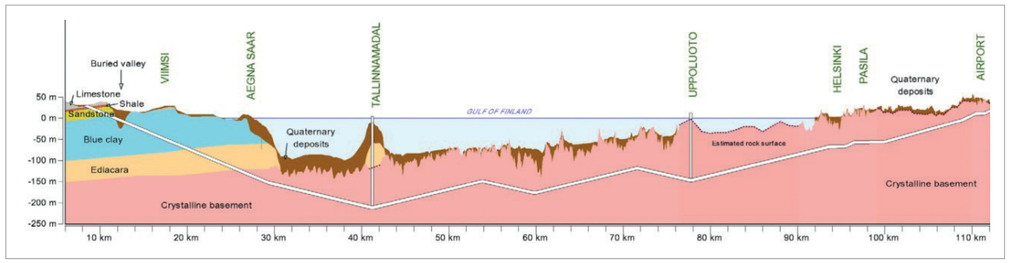
Geological section of the Helsinki-Tallinn undersea rail link project



Norway awards Vestfold rail works

Patrick Reynolds for *TunnelTalk*

Both contracts for tunnel works on the Drammen-Kobbervikdalen section of the Vestfold rail line in Norway have been awarded to local contractor Veidekke.

Client Bane NOR selected Veidekke for the engineering, procurement and construction (EPC) contracts to excavate the single-tube, double-track 6km long rock tunnel for a contract value of NKr1.96 billion (USD$213 million), and the contract for two shorter soft ground tunnels for NKr1.83 billion (USD$200 million).

With a contract value almost as much as the larger contract, complicated geology with clay or sand over solid glaciofluvial deposits requires challenging soft ground excavation and a cut-and-cover box section for the two shorter tunnels. The 123m^2 rock tunnel will be lined to 93m^2. Planning work, including the integration of a building information modelling (BIM) system, is underway towards start of construction of the near total 11km of tunnelling.

Main construction is due to start in April 2020 with the work due for completion in 2024. ■

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Oslo selects TBMs and segments for new water project

Shani Wallis, *TunnelTalk*

Two double shield TBMs with a precast segmental lining are selected by the Municipality of Oslo to excavate a 19km long raw-water supply line for the city of Oslo. The TBMs, one working from the fresh water intake in the Holsfjorden lake to the west and the other from the treatment plant site at Huseby in Oslo, will progress towards an in-tunnel breakthrough and install the permanent precast segmental lining to a minimum i.d. of 3.6m.

"Both drill+blast and TBM excavation was considered for the project," explained Project Director Steinar Johannessen, "and all comparables came down in favour of the TBM option with a precast segmental lining. The TBM option provided a robust and lower cost expectation for meeting the programme, and avoided an intermediate adit and working jobsite in one of the three municipalities under which the alignment passes. The circular profile of the TBM drives with the precast lining also reduces the head-loss on the gravity flow of the water conveyance and optimises the excavation cross section. The TBM option is about 60% of the face area required for a drill+blast option."

With the new infrastructure programmed to be in operation by 2028, approval of the environmental and social impact statements, and of the estimated 85%-probability investment of NKr12.5 billion (about USD$1.36 billion), is anticipated from the Oslo Municipality to permit invitation of tenders for the contracts so construction can begin in 2020. The conveyance tunnel will be let as a single contract on a bill of quantities and according to the standard Norwegian NA 8405 form of contract.

Application of a TBM excavation and segmental lining follows the successful use of double shield TBMs and the precast segmental lining for the recent Follo Line twin tube railway project in Oslo. The two TBMs of about 4.5m-5m in diameter for the water project will work through complex rock geology at up to 350m below the surface, and will encounter the potential for high volume, high pressure water ingress and rock instability. As on the Follo Line, extensive horizontal pre-excavation grouting and systematic probing will be part of the excavation process.

"Systematic pre-excavation grouting is expected for about 70% of the alignment," said Johannessen, "particularly from the inlet heading where anticipated water ingress must expect pressures of up to 35 bar. For this reason we have specified large capacity, high performance drilling and grout pumping equipment on the TBMs."

For the segmental lining, two types have been designed. A lining with gaskets will provide a watertight lining for about 3km of the tunnel under dense urban areas at the treatment plant end of the project. This will protect the natural groundwater regime and prevent any ingress contamination of the raw water conveyance. A non-gasketed, draining liner is designed for the remainder of the alignment to the intake. "A watertight lining for the reaches under open country is not required," said Johannessen. "The systematic pre-excavation grouting through areas of high ingress will control potential ground water inflow to within environmental protection and operational regulations."

"With no prequalification process, there has been keen interest in the project from Norwegian and European TBM construction contractors," said Project Manager Fredrikke Syversen. "Tender documents are expected to be released by end of the first quarter of 2020." Both Syversen and Johannessen worked previously on the Follo Line project for the railway authority Bane Nor and bring their experience to the new water project.

Tunnelling works on the project are due to start by summer 2020 and are programmed to take approximately four years to complete. ■

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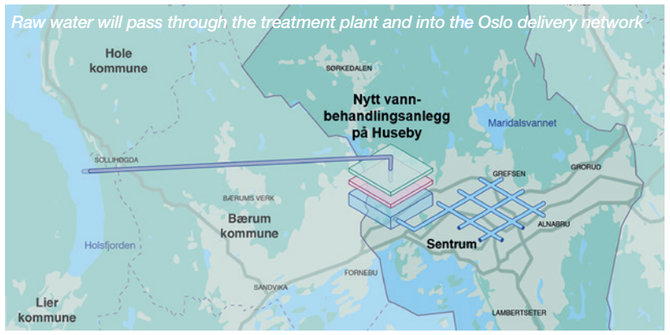
Raw water will pass through the treatment plant and into the Oslo delivery network



From left: Shotcrete on roundabout rock pillar; Artist's impression of the roundabout cavern and its rock pillar support

Subsea links for Faroe Islands

Patrick Reynolds for *TunnelTalk*

Design features of the Eysturoy subsea road link on the Faroe Islands include an underground roundabout and bifurcation to portals on different islands. The 11.2km long route connects the Faroese capital, Torshavn, with both sides of the Skala fjord to the north (Fig 1). In accessing both sides of the fjord, the project faced the unusual challenge of creating an underground roundabout, supported by a rock column left in situ.

The construction contract was awarded to NCC of Norway in late 2016 together with a second subsea route to the south of Torshavn running from Gamlaraett on Streymoy to Tradardulur on Sandoy. The client, ESTunlar, was set up by the Faroese Ministry of Industry to own, build, and operate both the Eysturoy and Sandoy toll roads. Geotek is the engineering geology consultant for the client. The Eysturoy link advanced ahead of the 10.5km Sandoy route and achieved final breakthrough in June despite some challenging conditions.

Geology along the Eysturoy route, with its deepest point at 189m below the seabed, is primarily basalt. The single-tube, two-lane, bi-directional tunnel has the standard Norwegian T10.5 profile of 82m^2 in cross-section and 10.5m wide at road level.

"Construction on the Eysturoy project began in early 2017 using two Atlas Copco XE3 jumbos, with wire mesh and shotcrete support and rock bolting as required," said NCC Project Manager, Alf Helge Tollefsen. "One of the main challenges was that much more pre-excavation grouting was needed than expected." Approximately 7,500 tonne of grout was used on Eysturoy, "considerably more than was typical for two earlier road tunnels on the Islands."

Construction of the roundabout with the profiled rock pillar in the cavern was an unusual challenge. "The rock quality was quite good but the roundabout was systematically grouted," said Tollefsen. Standard excavation was performed "but with focus on smaller sections, with immediate bolting and shotcreting, these elements together were quite complex."

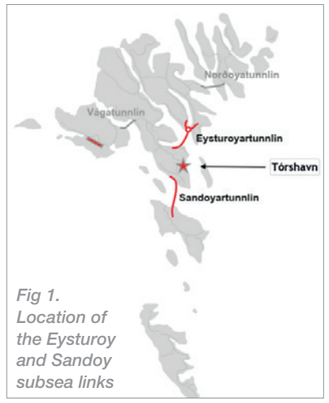


Fig 1. Location of the Eysturoy and Sandoy subsea links

The NCC team is also managing construction of the Sandoy project with the lowest point at 157m below the sea bed. Following completion of the main excavations at Eysturoy in June, the two Atlas Copco jumbos were moved across the islands to begin blasting at Sandoy.

Local company Jardfeingi completed geological investigations, Norconsult performed the tunnel design, and Sintef acted as technical advisor.

NCC completed the 4.9km long Vaga and 6.2km long Nordoya subsea road links on the islands in 2002 and 2006. Road tunnel construction on the archipelago of 18 islands began in the 1960s and there are plans for about 30km of additional subsea road connections. ■

References

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Norway trims ship tunnel cost

Patrick Reynolds, *TunnelTalk*

The cost of the long-planned 1.7km long, 36m wide x 50m high ship tunnel project in Norway has been significantly reduced and awaits the next round of the national budget approvals for advance into the procurement phase.

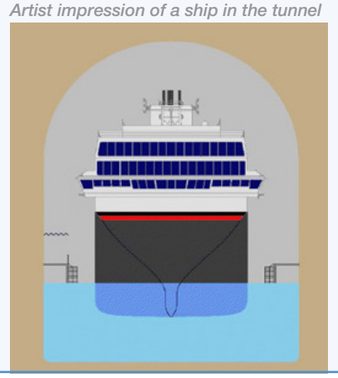
Terje Andreassen, Project Manager of the Norway coastal agency Kystverket, said: "That means potential contract award and start of excavation in 2022, if the project is approved in late 2020."

In May 2018, after five years of Phase 1 geological investigations and a second round of external quality assurance studies by Atkins and Oslo Economics, the project was estimated to be about a third more than the NKr2.7 billion (about USD$320 million in 2016 prices) allowed in the national transport plan.

Based on the Phase 2 findings, the Ministry ordered a rethink to bring the estimate back into line with the national transport plan.

The outcome was a revised estimate of just less than NKr2.7 billion (USD$295 million in 2019 prices), beating the allowable level in the earlier 2016 prices. The gap is even greater when the level is price-adjusted to almost NKr3 billion (USD$328 million) in 2019 prices.

Artist impression of a ship in the tunnel



Consultants advising on the overall design are Norconsult, Dr Techn Olav Olsen, and Snøhetta.

A key strategy to cut project costs was to get more and better geological data using longitudinal steer-drilling for core sampling along much of the tunnel length, working from each portal area, Andreassen told *TunnelTalk*.

Kystverket hired contractor Diamant Wire Teknikk to perform the longitudinal core drilling, and drill steering was carried out by Devico AS.

Andreassen told *TunnelTalk* that expert help on the extra geological studies in the gneiss and slate involved assistance from Multiconsult and Sintef.

Limited time resulted in only 60% of the alignment being probed. The core samples are 50mm in diameter and 1m in length, and are taken from along a path steered to run under the centre of the tunnel crown. Following core sampling, groundwater inflow tests were performed along the boreholes at the actual depth of the tunnel.

The previous site investigation mainly performed limited inclined core drilling close to the portal areas, said Andreassen. Investigation also included refraction seismic investigations above where the portals are to be excavated.

Andreassen said findings "did not change the understanding of the geology but we obtained more precise information about the amount of different rock types, and information on cracking and the orientation of gaps."

The more precise data on rock type, characteristics and stress distribution, and location of weak zones, have reduced uncertainty and risk for future tunnelling works which call for large, multiple bench excavations and some use of pre-excavation grouting in weaker zones.

Andreassen acknowledged the improved understanding of the geology would allow for better, faster tunnelling progress but said client planning did not address construction time, but focused on the cost/m^3 of drill+blast excavation.

Other factors in helping to reduce projected costs include:

- shorter quay approaches at the portals;
- simplifying the entrance structures;
- introducing computer-assisted sailing;
- modifying construction of the Molde portal;
- minor changes to the ship guide structure along the tunnel; and,
- removal of a walkway in the roof.

Project planning for the construction phase includes a service adit to support excavation logistics.

Kystverket plans to award the works as a single design-build contract with the client retaining all geological risk, confirmed Andreassen.

Excavation is expected to take three years, including blasting and dredging of the temporary coffer dams at the portals to allow excavation to more than 13m below mean sea level. The overall project is planned to take four years to complete.

While there are tunnels for small boats and barges in different parts of the world, Andreassen said "nothing exists for passage of large ocean-going vessels such as being planned by Kystverket." ■

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Route of the ship tunnel

Norway delays Rogfast procurement for a rethink

Patrick Reynolds for *TunnelTalk*

Main construction of the Rogfast undersea road project in Norway suffered a delay when the National Roads Authority (NPRA) cancelled bids for the first contract.

Of three bids submitted for the middle Kvitsøy Contract E02 for the 26.7km long subsea crossing, two, from PNC Norge and from Salini Impregilo, did not fit within the accepted construction period and the other, from the Impenial/Stangeland JV, came in at 29% higher than the NPRA NKr3.5 billion (USD$340 million) estimate. Two other bids from Skanska and Marti did not reach the price offer stage. The NPRA decision to exclude the two bids was not contested.

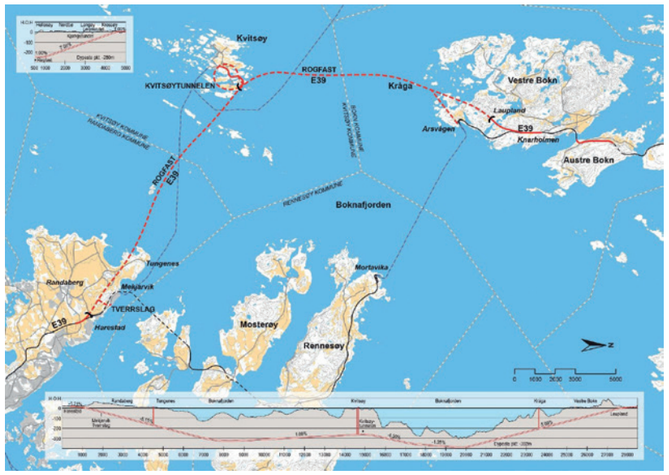
In a statement, NPRA Director Bjørn Grimsrud said "we have made an assessment that shows there is a risk that the project as a whole cannot be implemented within the limits set."

NPRA spokesman Kjell Bjørn Vinje told *TunnelTalk*, "new calculations related to costs are ongoing." Project spokesman Øyvind Ellingsen told *TunnelTalk*, "we will look at all the contracts to review the design solutions" and added that "it is too early" to say if these outcomes would affect all lots.

The Kvitsøy Lot represents about one-third of total excavation for the project, requiring about 21km for access and the twin main tubes. The other two lots are Harestad Contract E03 and Laupland Contract E04 (Fig 2).

Rogfast will be the longest undersea road tunnel in the world, with twin T10.5 profile excavations running 26.7km under the Bokna Fjord, near Stavanger. It has a budget of NKr17 billion (USD$1.65 billion) and forms a strategic part of the E39 West Coast Highway for Norway. Contract E02 includes 21km of drill+blast excavation to create access to Kvitsøy Island and build ventilation shafts for the twin tubes.

Following market discussions, five contractors registered expressions of interest in the estimated NKr3-3.5 billion (USD$290-340 million) E02 Kvitsøy Lot. In February 2019, the number was shortlisted to three with the bids from PNC Norge and Salini Impregilo groups being eliminated.



Top: Fig 1. Scope of the Rogfast Contract EO2 Kvitsøy Lot
Bottom: Fig 2. Route of world record Rogfast undersea road link

The E04 lot involves 19km of main tunnel excavations with another 16km of the main tunnel required under the E03 Harestad Lot.

While excavation works on the small Arsvågen and Mekjarvik lots at either end of the subsea link and in preparation for the E03 and E04 contracts have been completed, Rogfast procurement plans have experienced a run of delays. In 2017, when Parliamentary approval was received, the crossing was expected to open in 2024. Most progress was made in 2019 with bids, finally, invited and received for the first time. The Kvitsøy contract cancellation leaves in doubt the latest timetable to open the project in 2026. ■

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From left: Completion of Arsvågen contract, May 2019; Earlier drill+blast works on Mekjarvik and Arsvågen Lots

UK Government agrees to progress HS2

Lauren Dyson, *TunnelTalk*

Despite a revised cost estimate of £106 billion, the UK Government has agreed to progress the full scope of Phase 1 of the dedicated high-speed HS2 railway project that will connect London with Birmingham. Phase 1 of the project comprises 225km of twin highspeed rail track and four new stations at London Euston, Old Oak Common in west London, an interchange station near Birmingham Airport, and a new station on Curzon Street in Birmingham.

Legislation for Phase 2a of the project to continue the line from Birmingham Midlands to Crewe is currently awaiting Parliamentary approval, and Phase 2b to connect Crewe to Manchester, and join the West Coast mainline to Leeds, is also in planning and design.

There has been much criticism surrounding the plans for HS2, particularly with regards to sustainability and rising costs to be funded by the UK taxpayer. When HS2 was first proposed in 2012, the budget was £32.7 billion. This was revised in 2015 to £55.7 billion and in July 2019, an announcement from HS2 Ltd, the organisation set up to design, build and deliver the project, said that an additional £30 billion may be needed to complete the full scope of Phases 1 and 2 (Table 1).

In response to criticism about the financial and environmental sustainability of HS2, the Government ordered a review of the project chaired by Douglas Oakervee, a former Chairman of HS2 Ltd. The report estimated that the total cost of the HS2 project could now reach £106 billion. Despite this, the 10-member review panel, with the exception of Deputy Chair Lord Berkeley, recommended that the project should proceed as planned.

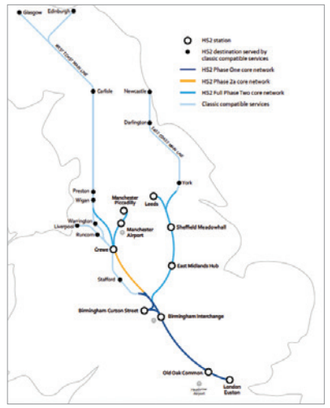
The Oakervee panel found that a "key driver behind the inflated prices on Phase 1" had been "considerable over-specification and gold-plating in contracts with much of the design seemingly done on a worst-case, risk-averse scenario." These design standards and specifications could be reduced to be less severe without major risk, but there would be a trade-off between cost and schedule. Constraints in the Phase 1 Act that approved construction of the line, and the difficulty in changing it, also do not assist the taxpayer. There are opportunities, it states, on Phase 2b to remove gold-plating and over-specification and alond with the redesign of alignments.

Table 1. HS2 cost increases

Element of cost estimate	Cost change since April 2017		Cost estimate in October 2019
	(£ million)	(%)	(£ million)
Main civil construction	4,916	85	10,667
Station design and build	1,020	34	3,984
Railway systems	961	52	2,792
Preparatory works	860	124	1,552
HS2 Ltd costs: HS2 Ltd Staff and administration	814	35	3,138
On network works (ONW) and wider network works (WNW)	721	85	1,573
Utility diversions	389	81	869
Land and property acquisition	154	5	3,562
Other	609	180	948
Trains (rolling stock) and operations and maintenance	-390	-20	1,584
Total	**10,054**	**49**	**30,669**

Table 2. HS2 appointed designers and contractors

Phase 1 Station designers	
London Euston	Arup
Old Oak Common	WSP
Birmingham Interchange	Arup
Birmingham Curzon Street	WSP
Phase 1 Station preferred contractors	
London Euston	Mace – Dragados JV
Old Oak Common	Balfour Beatty, Vinci, Systra JV
Phase 1 Main line preferred contractors	
S1 Euston tunnels and approaches	Skanska, Costain, Strabag JV
S2 Northolt tunnels	Skanska, Costain, Strabag JV
C1 Chiltern tunnels and Colne Valley District	Align JV of Bouygues, Volker Fitzpatrick, Sir Robert McAlpine
C2 North Portal of Chiltern tunnel to Brackey	Eiffage Kier JV
C3 Brackley to South Portal of Long Itchington Wood Green tunnel	Eiffage Kier JV
N1 Long Itchington Wood Green tunnel to Delta Junction and Birmingham Spur	Balfour Beatty, Vinci JV
N2 Delta Junction to West Coast Mainline tie-in	Balfour Beatty, Vinci JV
Phase 2b Civils design and environmental services	
Lot 1	Mott MacDonald and WSP
Lot 2	AECOM, Capita and INECO
Lot 3	Arup



Full scope of the HS2 project

A 2019 report by HS2 Ltd identified a number of reasons why Phase 1 cost forecasts are more than the available funding. These include costs associated with security, design and logistics for contractors, which have turned out to be higher than anticipated, and that estimates for contractor overheads and design costs, based on previous projects, were underestimated, particularly in respect to station costs.

Other reasons include the cost of power, signalling and communications systems, which are fitted to existing infrastructure, and development of the design leading to a better understanding of the work required. Site complexity has also been greater than anticipated, as a result of the discovery of asbestos and archaeological remains, and work to modify existing Network Rail assets at Euston and Old Oak Common to enable high-speed services is more complex than originally considered.

Designers and preferred contractors for Phase 1 are all appointed and are working with HS2 Ltd to advance Phase 1 between London and Birmingham according to estimates and schedules (Table 2) and to have it operational by late 2026. ■

References

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- HS2 announces enabling works contractors – *TunnelTalk*, December 2015
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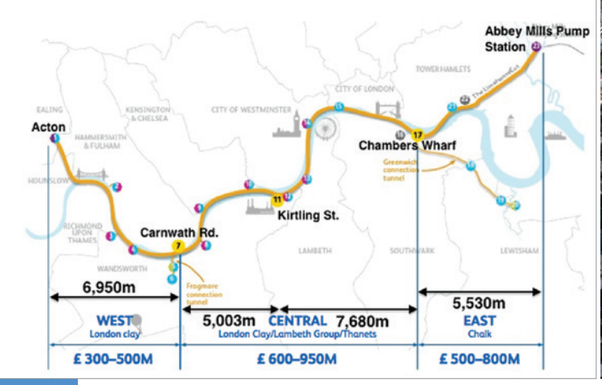

From left: Fig 1. Tideway route under the Thames; Chambers Wharf job site; One of four main route TBM drives

Tideway more than a third through TBMs drives

Jonathan Rowland, *TunnelTalk*

With one TBM drive complete and two others underway, excavation of the 25.5km Tideway CSO route was well into excavation by early 2020. In addition to the main alignment, the three Tideway contracts include 22 shafts and nine lateral connectors. From 33m deep at Acton in the west, to 66m deep at Abbey Mills in the east, the main 8.8m o.d. (7.2m i.d.) gravity CSO interceptor tunnel falls at a gradient of 1m in 790m. From Abbey Mills, Tideway joins the existing Lee Tunnel for onward flow to the Beckton treatment works (Fig 1).

Central Contract

The first TBM to breakthrough was one of two NFM EPBMs working on the Central Contract for the Ferrovial-Laing O'Rourke FLO JV. The TBM finished its 5km x 7.2m i.d. bore on the westward Kirtling Street to Carnwath Road section in November 2019 (Fig 1). At the end of its drive, it was stripped of its parts, turned aside and buried. The rear gantries were removed back through the drive and the Kirtling Street launch shaft. The connection to the Carnwath Road shaft will be excavated by hand and finished with a secondary sprayed-concrete lining. This end of drive process was required because the Carnwath Road shaft is the working shaft of the West Contract TBM. All other Tideway TBMs will break through into their reception shafts.

The second NFM EPBM on the Central Contract launched in March 2019 on its 7.7km drive eastward from the Kirtling Street launch shaft to the reception shaft at Chambers Wharf. Progressing at a rate of 20m-25m/day, the machine broke though at the Blackfriars Bridge intermediate shaft for scheduled maintenance ahead of expected final breakthrough at Chamber Wharf in late 2020.

West Contract

On the Carnwath Road to Acton Storm Tanks alignment, the BAM Nuttall-Morgan Sindall-Balfour Beatty JV has its Herrenknecht EPBM more than half way into its 7km drive. The TBM is progressing primarily through London Clay at a rate of 20m-25m/day and is expected to breakthrough in late 2020 or early 2021.

Also on the West Contract, a refurbished Lovat TBM completed its first drive for the 1.1km x 2.5m i.d. Frogmore connector in October 2019. After completing the first 500m drive, the machine was transported back to the central Dormay Street shaft and relaunched at the end of January 2020 for the north drive to the main Tideway tunnel.

The Hammersmith connector of the West Contract intercepts flows from the Hammersmith pumping station where an average 2 million m^3 of untreated sewage discharges into the Thames annually.

The Hammersmith project included an interception chamber, a 35m deep x 11m i.d. drop shaft, a 48m long x 5m i.d. dearation chamber and a 250m x 4m i.d. connection tunnel to the main sewer (Fig 2). Excavation was advanced using the SCL sprayed concrete lining method through London Clay and finished with an insitu concrete secondary lining.

Initial design called for a waterproofing membrane to meet water ingress/egress specifications of 0.1 litres/m^2/ day on average, or 0.2 litres/m^2/day over any 10m section. This was later replaced with a 5kg/m^3 dosage of Xypex crystallising agent in the primary lining shotcrete. When completed, the primary lining had no measured water ingress in the shaft against a maximum allowable ingress of 106 litres, given a surface area of 1,060m^2. In the tunnel, 9 litres of water ingress was measured against allowable ingress of 434 litres given a surface area of 4,341m^2. Any damp spots were injected with resin grout, after which the tunnel was signed off as watertight.

The secondary insitu concrete lining was cast using a PLC-driven 6m long formwork with automatic spud bars. Supplied by Kern Tunneltechnik, this is believed to be the first formwork to have an integrated PLC, allowing semi- and fully-automatic operation.

Other connectors on the contract have been excavated using pipejacking machines including two drives of 200m and 134m long at Putney to link CSOs to the main Tideway tunnel.

East Contract drive

Excavation on the East Contract by the Constain-Vinci-Bachy Soletanche CVB JV using two Herrenknecht slurry TBMs is expected to begin in 2020. The TBMs will complete the 5.5km of the main 7.2m i.d. Tideway alignment between Chamber's Wharf and Abbey Mills pumping station and the 5.5m i.d. x 4.6km long Greenwich connector tunnel (Fig 1).

Geology along the routes comprises Seaford Chalk in which external water pressures of up 5 bar will be experienced. The first TBM for the Greenwich connector arrived onsite in 2019 and is expected to launch in mid-2020. The second TBM, for the main alignment west from Chambers Wharf to Abbey Mills is expected to arrive on site later in 2020.

Expenditure and progress

By September 2019, capitalised expenditure on the projected totalled £2.218 billion with costs on track to remain in line with the revised £3.8 billion estimate stated in the 2018/2019 Project Annual Report. Despite the complexity of the project, and a shutdown of several weeks in early 2020 due to the coronavirus pandemic, Tideway reports that it is making good progress towards its scheduled finish in 2024. ■

References

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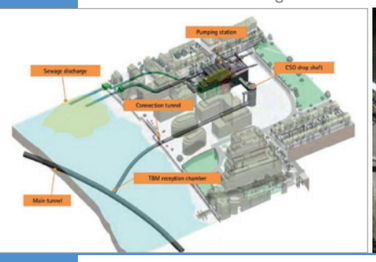

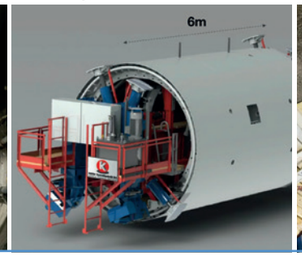

From left: Fig 2. Hammersmith connector; Waterproof shotcrete lining; PLC formwork; Formwork spuds and stopend

Patrick Reynolds for *TunnelTalk*

Silvertown PPP procurement

A £1 billion PPP public-private-partnership contract for the Silvertown road tunnel under the River Thames was signed by Transport for London (TfL) and its concession partner RiverLinx, a consortium of Macquarie Capital, Cintra of Spain, Aberdeen Standard Investments, BAM PPP-PPGM JV and SK E&C of Korea. Construction of the 1.4km long twin-tube link, close to the existing 122-year old Blackwall road crossing under the Thames, is due to start in 2020 towards opening in 2025, with the design-build-finance-operate-and-maintain concession running for a further 25 years.

After naming the preferred bidder, contract signing was held up when the losing bidder Silver Town Connect (STC), comprised of Iridium Concesiones de Infraestructuras, Hochtief PPP Solutions, and subcontractors, Dragados and Hochtief Infrastructure, lodged a claim against the procurement process and award decision. It claimed that its bid scored only fractionally behind the Riverlinx bid and had scored higher in price evaluation, which had most weighting in scoring the bids. It noted lower scores in two areas concerning critical consents and ground condition rates.

STC subsequently removed the block on award of contract but upheld its complaint. TfL said it would continue to discuss the outstanding issues with STC and defend its approach robustly.

With the STC block lifted and with close on equity and debt funding for the project, the contract with Riverlink was signed in later 2019.

Reference design for the tunnel was completed by a group led by Atkins. Cintra Global of Spain has engaged designers COWI and Arup to complete the design-build detailed design for Riverlinx. One TBM of about 11.5m diameter is expected to be procured to excavate the 1.2km TBM drives between cut-and-cover approach ramps in Greenwich and Silvertown (Fig 1). The two two-lane bores will be connected with a set of cross passages.

The procurement process began in October 2016, envisaging 4.5 years in construction and a 25-year operation and maintenance period. The UK Government Department for Transport approved the project in May 2018.

The new crossing will ease chronic peak traffic congestion at the existing Blackwall road tunnel and at the Dartford bridge and tunnel crossing on the M25 London orbital motorway. Challenges for the tunnel constructors will include the potential for undiscovered ordinance in an historically heavily bombed part of London during WWII, contamination of the ground in what was an industrially developed part of the city and location of a hazardous material factory close to the south portal of the project. The area of the project is also influenced by more recent infrastructure including the Docklands Light Railway and its Woolwich branch viaduct, and the Emirates Air Line cable car link across the river on approximately the same route as the new tunnel. ■

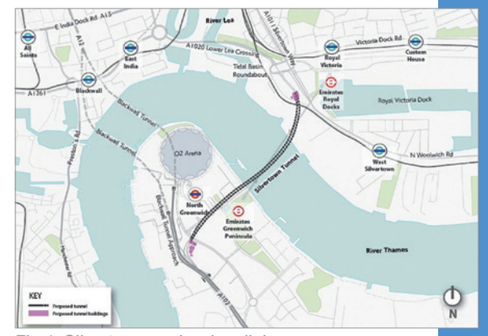

Fig 1. Silvertown under river link

References

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London adds to cable tunnel network

Karen Martin, *TunnelTalk*

Design-build construction of the latest cable tunnel under London is awarded to the Hochtief-Murphy JV and construction on the six-year £400 million contract project should begin in early 2020.

The total £1 billion, eight-year project for the National Grid will see the construction of a 32.5km tunnel from Wimbledon in the southwest, to Crayford in the southeast (Fig 1). The project follows successful completion of a £1 billion seven-year London Power Tunnels Phase 1 project and adds to more than 200km of electricity cable tunnels under London built since 1992.

The 3m and 3.5m diameter tunnels will run 10m to 63m deep with the majority at about 30m deep, and will replace three sections of power transmission cables that currently run under local roads.

Intermediate shafts are required at key points with permanent access headhouses required on several shafts. National Grid intends to build the tunnels and shafts under its permitted development rights, with planning permission required for the headhouses on the shafts not located on National Grid operational land.

Phase 1 of the project was the first major investment in the high voltage electricity delivery system for London since the 1960s. The project, constructed by the Costain/Skanska JV, runs 32km from Hackney in the northeast to Wimbledon in the south. The route passed under existing underground infrastructure including water and sewer tunnels, and the London Underground and Crossrail transport networks.

The 3m and 4m diameter tunnels host almost 200km of 400kV cable with shafts along the route, allowing easy access and ventilation of the heat generated by the cables.

In preparing for Phase 2, National Grid is one of four early adopters to begin implementing the new Project 13 approach to delivering infrastructure. Launched by the Institution of Civil Engineering, Project 13 is based on an enterprise, rather than a traditional transactional arrangement, and provides the possibility to draw on best practice from across the industry in order to boost certainty and productivity in delivery, improve whole life outcomes in operation, and support a more sustainable, innovative, highly skilled industry. All contracts for Phase 2 of the project are based on the NEC4 design-build terms and conditions.

The two other joint ventures in the bidding for the Phase 2 contract were the Balfour Beatty/Ghella JV and a Morgan Sindall/BAM Nuttall JV. The selected JV team of Hochtief and Murphy have a strong track record of working together on major London projects, including the Channel Tunnel Rail Link and the Crossrail Thames Tunnel project. ■

References

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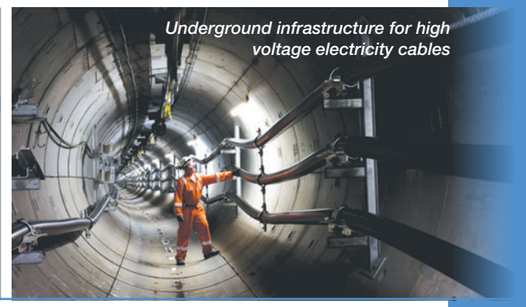
- Second drive through on London cable link – *TunnelTalk*, March 2013

Fig 1. High voltage cable route and headhouse locations



Underground infrastructure for high voltage electricity cables

Procurement underway for Stonehenge road bypass

TunnelTalk reporting

After UK Government agreement to fund construction of the long-awaited A303 Amesbury to Berwick Down road upgrade scheme passing the ancient Stonehenge monument in south England, an 18-month procurement process to find potential contractors for the project was advanced. The proposed upgrade includes a 3.3km long twin-bore tunnel that will follow closely the existing A303 route. This is longer than the 2.9km tunnel previously proposed as a result of optimising the portal locations, best integrating the scheme into the surrounding landscape, avoiding important archaeological sites and preserving views of the setting sun from Stonehenge during the winter solstice.

Following a call for submissions at the end of 2019 to undertake the planned design-build of the project, Highways England, the project owner, selected three international joint ventures for the next stage of the procurement process:

- BMJV - Bouygues Travaux Publics and J Murphy & Sons;
- HDJV - Hochtief Infrastructure and Dragados;
- MORE JV - FCC Construcción, Salini Impregilo and BeMo Tunnelling UK.

The £1.25 billion main works contract for the construction of the civil, structural, mechanical, electrical and technology components of the tunnel includes the approach roadworks and structures and the environmental components of the scheme.

From April 2020, the three JVs will be invited to participate in a dialogue with Highways England over a six-month period before submitting their final tenders. The preferred bidder is expected to be announced in 2021.

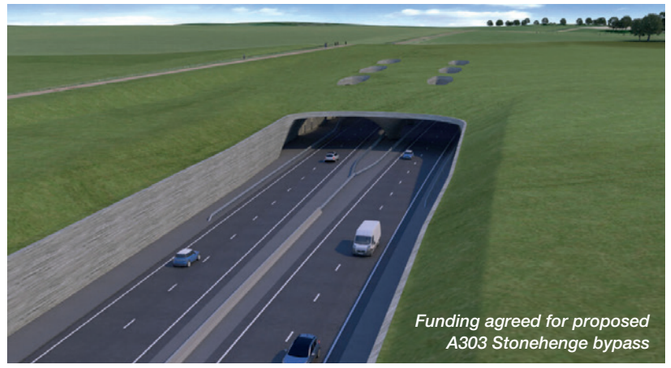
The choice of excavation method, between TBM or an open face SCL, is for the joint ventures to select and present in their proposals.

Highways England Project Director Derek Parody said: "We are looking forward to entering into a competitive procurement process, subject to planning consent being granted by the Planning Inspectorate.

"We are currently assessing the programme timescales," he continued, "and anticipate awarding the contract for main works in 2021 and for them to continue until 2026."

Following a six-month development consent order examination in 2019, the Planning Inspectorate has sent its report and recommendation to the Secretary of State for Transport for UK Government approval. "We welcome the Government funding commitment for the upgrade and await the decision from the Secretary of State on our development consent order application," said Parody.

Contracts for enabling preliminary work will be procured separately, as part of the total £1.7 billion capital cost of the project. ■



Funding agreed for proposed A303 Stonehenge bypass

References

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River Humber gas pipeline breaks through

TunnelTalk reporting

National Grid and the Skanska/Porr/AHak JV celebrated breakthrough of the 5km tunnel to house a replacement gas pipeline 30m beneath the River Humber. The Herrenknecht TBM, designed for the 3.65m i.d. project, completed excavation on 10 September 2019. Breakthrough into the Paull shaft on the north bank of the river marked the end of an 18 month drive and start of installation of what the project claims will be the longest hydraulically inserted pipeline in the world.

National Grid awarded the design-build contract for the new high pressure gas pipeline in May 2016, and tunnelling work began in April 2018. The pipeline on the east Yorkshire coast will carry about 25% of the gas to supply homes and businesses across the east of England and beyond.

The Herrenknecht TBM excavated mostly chalk, which was graded and reprocessed to restore a former quarry near the Humberside Airport.

In Spring 2020, work will begin on site to push eight 610m long x 850 tonne sections of pipe on rollers into the new tunnel. Two hydraulic thrust machines will push the pipes at about 1m/min into the tunnel, which will be flooded with water to aid installation and provide the long-term backfill medium around the installed pipeline. When one pipe section has been installed, the next will be moved into position, welded to the one in front, and the push will continue until all 5km of pipeline is installed beneath the river.

The old pipeline across the River Humber is in a trench just below the river bed. Over time, tidal patterns have eroded the river bed, risking its exposure. ■

References

- Contract award for 5km Humber tunnel – *TunnelTalk*, April 2016

From left: Segmentally lined gas pipeline host tunnel; Underwater breakthrough into the water-filled Paull shaft

Anglo American buys out Sirius Minerals

Karen Martin, *TunnelTalk*

Following advanced discussions and a proposed offer earlier in January 2020, Anglo American finalised its take over of Sirius Minerals and its Woodsmith potash mine development project in the UK in March 2020. Under the agreement, Sirius shareholders will receive 5.5 pence per share, valuing the share capital of Sirius at about £405 million.

Russell Scrimshaw, Chairman of Sirius, acknowledged that the returns that the offer represents are "not what either our shareholders or the Sirius Board had previously hoped for," but the Anglo American offer is "the only feasible option."

Following setbacks in the bond market towards the end of 2019, Sirius initiated a strategic review and received an alternative financing proposal from Anglo American in December 2019 ahead of the end of March 2020, when its operation finances were due to run out. "The only viable proposal was received from Anglo American in early January, who were only interested in pursuing a 100% control transaction," explained Scrimshaw.

Mark Cutifani, Chief Executive of Anglo American, said, "We intend to bring the financial, technical and product marketing resources of Anglo American to the development of the project."

As the March financial deadline loomed, construction at Woodsmith Mine was ongoing. Project owner, Sirius Minerals, announced that, in April 2019, it secured a commitment letter with JP Morgan in relation to a USD$2.5 billion rolling credit facility (RCF) drawdown which was subject to a number of conditions, the most significant being the successful issuance of USD$500 million of senior secured notes.

In September, the company Directors concluded that completing financing to satisfy the terms of the RCF commitment letter was unlikely before it expired as a result of global market conditions, plus the political environment and ongoing uncertainty surrounding Brexit.

A decision was made to reduce the pace of development to review available options. Cash flow forecasts indicated sufficient liquidity to continue to operate and meet liabilities until March 2020.

Meanwhile, construction started at each of several construction sites.

Following award of Drive 1 of the mineral transport system (MTS), Strabag was awarded Drives 2 and 3, expanding its involvement to a €1 billion contract. Drive 1 is the remaining 24km of the 37km MTS, between the shaft at Lockwood Beck and the Woodsmith Mine. Drives 2 and 3 advance a 13km section of the MTS from the tunnel portal at Wilton to Lockwood Beck.

The MTS is being excavated at a depth of 360m within dry Redcar Mudstone and aligned to avoid water-bearing rock and abandoned mine workings. The 6m diameter Herrenkencht Drive 1 TBM launched from Wilton, Teesside, in April 2019 and was reported to be more than two months ahead of schedule before the project slow down.

Two further machines were due to be launched from Woodsmith Mine and Lockwood Beck in early 2020 to complete the remaining 24km of the 6m i.d. tunnel. Advance rates on Drive 1 could remove the need for the planned TBM2, enabling Drive 1 to continue through Lockwood Beck to connect with Drive 3 TBM from Woodsmith Mine.

The 360m deep intermediate access shaft at Lockwood Beck has been excavated and lined to 51m deep. Grouting has commenced to prepare the ground ahead of the main shaft sinking to depth using a drill+blast Galloway. The temporary headframe is being erected and construction of the winder house has progressed on schedule. Should TBM2 still be required, shaft bottom works will be undertaken before the shaft is handed over from shaft sinking contractor DMC to Strabag to begin construction of the launch cavern for Drive 2.

At the Woodsmith Mine site, a Herrenknecht vertical sinking machine (VSM) excavated the first 115m of the 360m MTS shaft. The Galloway is being prepared to begin drill+blast excavation to the 360m depth.

The main production and service shafts at Woodsmith Mine are being constructed to a depth of 1,600m. Excavation of the 35m diameter service shaft foreshaft to 45m was completed earlier in 2019, while excavation of the 6.75m i.d service shaft has reached its target depth of 118m using conventional excavation techniques. A Herrenknecht shaft boring roadheader (SBR) will excavate both shafts to their full depth. Preparatory works are almost complete to enable construction of the SBR headframe and installation of the machine into the foreshaft, with the permanent winder for the service shaft now in place.

Excavation of the 32m diameter production shaft foreshaft has progressed faster than expected to its target depth of 45m. The production shaft has diaphragm walls installed to a depth of 120m. Along with excavation of the 6.75m i.d production shaft, construction of its permanent winder building is almost complete. It will hoist excavated muck to the surface from the shaft sinking SBR operations, and in full operation will hoist polyhalite for many decades to come.

Continuing development of the project is now secure with the Anglo American takeover. ■

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- Shaft sinking operations at UK potash mine – *TunnelTalk*, April 2018
- First drive for UK potash mine awarded to Strabag – *TunnelTalk*, April 2018

Below: VSM being removed from Woodsmith Mine MTS shaft; Right from top: Main construction site of the Woodsmith Mine project; VSM after excavation; The MTS shaft

Russian cities plan major metro expansions

Eugene Gerden for *TunnelTalk*

Authorities of several Russian cities have announced plans for significant expansion of their metro systems. The cities with metro systems in Russia are Moscow, St Petersburg, Nizhny Novgorod, Novosibirsk, Samara, Yekaterinburg and Kazan (Table 1). There is a possibility of metro systems also for other cities with more than 1 million people, including Voronezh, Tomsk, Omsk and Tyumen.

Moscow has the most extensive existing metro system, comprising 327.5km of trackway and 222 stations, nearly all of which is aligned underground in a network of 88 deep stations and 123 shallow stations with another 12 stations on the surface and five elevated. The deepest station is Park Pobedy at 84m deep (Fig 1). According to statements by Moscow Mayor Sergei Sobyanin, the length of the Moscow Metro will be extended to 1,000km by 2023-2024.

Igor Arnautov, a senior analyst at Investkafe, said, "The majority of new stations in recent years are built at shallower depths using open cut methods. This is contrary to Soviet methods when the majority of underground metro stations of the city were built at great depths."

One of the main problems of the Moscow Metro currently, according to the Russian Ministry of Transport and Engineering, is its ventilation system, which cannot cope with the increase in temperatures in its very deep stations during the summer season.

Table 1. Underground sections of the existing metro systems in Russia

City	Total metro system	Total underground
Moscow	327.5km 222 stations	327.5km 213 stations
St Petersburg	118.6km 69 stations	112km 62 stations
Nizhny Novgorod	22.2km 15 stations	20km 14 station
Novosibirsk	15.9km 13 stations	14km 13 stations
Samara	11.6km 10 stations	10km 8 stations
Yekaterinburg	12.7km 9 stations	12.7km 9 stations
Kazan	16.9km 11 stations	15km 10 stations

Moscow expansion

One of the most ambitious projects in the history of the Moscow Metro is the 69km Bolshaya Koltsevaya rapid transit Circle Line with 31 stations. It is also claimed as the longest metro circle line in the world, overtaking the 57km Second Circle Line of the Beijing Metro, according to Marat Khusnullin, Deputy Mayor of Moscow for Urban Planning and Construction and the Moscow City Government official responsible for the project. The new Bolshaya Koltsevaya Circle Line (BKL) will save passengers the journey to the centre of the city in order to transfer from one radial line to another.

Plans to build the BKL were first proposed by the Soviet Government in 1985. Lack of financial resources just before and after the collapse of the USSR in 1991 caused suspension of the project. Interest in resuming the project was expressed by Mayor Sobyanin in 2011 and construction began in November of the same year.

Services on the first section of the line and its five stations were launched officially in February 2018, while commissioning of the entire line is scheduled for 2022. About 50% of the construction works for the project has been completed. Much of the line is sub-surface with works running at between 22m and 48m deep. According to Deputy Mayor Husnullin, particular technical difficulties are expected due to the difficult soils that include abrasive sandstone and clay.

Construction of the project is managed by Mosinzhproekt, which has completed some of the largest construction projects in Moscow in recent years. For the Bolshaya Kottsevaya Circle Line, Mosinzhproek and its affiliated construction companies are collaborating with Chinese engineering and construction companies which are engaged to build sections of the Line. For the works, China Railway Construction Corporation, CRCC, has delivered four 6m diameter TBMs for the project and is planning to deliver another larger machine at 10m diameter.

Xue Li Jiang, Executive Director and Chief Engineer of CRCC, said all five TBMs are designed to take into account the geological conditions and the city's climate. According to Xue, low temperatures during winter will not complicate planned works.

A total of 15 TBMs are required for construction of the line. This is the highest number of TBMs to be used at the same time in the history of Moscow tunnel excavation. Most TBMs for works in Moscow have been supplied by Herrenknecht from Germany, including two 10m machines that recently achieved breakthroughs. Import of TBMs from Germany is now barred under sanctions imposed as a result of Russia's annexation of the Crimea region of Ukraine in 2014.

Mars Gazizullin, Director General of Mosinzhproekt, said that deadlines for the new Circle Line, and particularly of its first section, have been extended several times, mainly due to various technical difficulties and challenging ground conditions. Much of the excavation is through limestone with high karst hazards and flowing groundwater.

"As the majority of the stations of the line are built at a relatively shallow depth, with only three at 65m-70m, the construction works are conducted in water-saturated soils and complex hydrogeological conditions," said Gazizullin. "In addition, there is a need to protect existing structures with comprehensive preventive measures."

According to Deputy Mayor Khusnullin, "80km of tunnel excavation was completed by mid 2019."

St Petersburg plans

In addition to Moscow, the Russian Federal Government is paying particular attention to expansion of the St Petersburg Metro. Currently the system comprises a total network of 118.6 km and 69 stations with most underground in 112km of tunnels and 62 underground stations.

The overall expansion project will extend the St Petersburg Metro from 124km to 156km by 2027. In addition, the number of stations will increase from 72 to 85, with 80 of the stations underground. Part of these plans includes the construction of new entrance halls and interchange stations. Total investment is estimated at more than RUB170 billion (USD$2.3 billion).

Under consideration, to accelerate the expansion of the metro, is construction of the Frunze radius line. One section of the Frunze-Primorsky Line 5 with three stations at Prospect of Glory, Danube, and Shushary, was completed at the beginning of October 2019. The cost of the extension was RUB34 billion (about USD$523 million) and will help connect the historical city centre to its north-western and southern districts.

Implementation of the metro project is expected to be carried out by Metrostroy, one of the largest engineering companies in Russia and the main contractor of St Petersburg Metro construction works. This is despite the fact that the local authorities have repeatedly announced their intention to end the monopoly of the company in the St Petersburg tunnelling industry.

Authorities say the local government is conducting talks with potential foreign construction and engineering companies including, for example, ICA Construction, a joint venture of IC Ictas Insaat of Turkey and Astaldi of Italy, which already has experience with major infrastructure projects in St Petersburg.

In the meantime, Metrostroy hopes to continue its participation in the project. The company plans to continue the use of its technology that significantly speeds up construction. These include a TBM supplied by Herrenknecht for excavation of a steep 30 degree x 140m long access decline into the Obvody kanal underground station on the Metro 5 Line in 2010, and for the access declines for the Admiralteyskaya and Spasskaya Stations.

Another innovative technology used on the St Petersburg Metro, was the 10m diameter EPBM used to excavate single-tube double-track tunnels. "This method accelerates construction of new metro running tunnels by almost 1.5 times," said Ekaterina Higinyak, Chief of the Public Relations Department of JSC Metrostroy. "The EPB technology also allows excavation of metro tunnels at shallow depths that seemed unrealistic previously."

According to experts at Metrostroy, open face excavation is possible in St Petersburg in the dry Cambrian clays and at a depth of 40-60m. Most of the works in the upper layers are usually complicated by a high content of groundwater. Therefore, most of the metro stations and tunnels under the river channels of St Petersburg are located at a depth of more than 50m.

From top left: St Petersburg Metro and planned expansions; Decline TBM drive; Inset: Herrenknecht TBM procured for excavations

Plans for Novosibirsk

In Novosibirsk, Russia's third largest city and a center of the Siberian agglomeration, authorities have announced plans to invest up to RUB20 billion (USD$300 million) to expand the city's metro. Currently, the system is 15.9 km long with 13 station and is mostly underground in 14km of running tunnels and with all stations underground.

According to Mysik, head of the Novosibirsk Construction of Underground Transport Facilities, a local state enterprise, the expansion plan includes two underground stations and a proposed 10km of TBM excavated running tunnels.

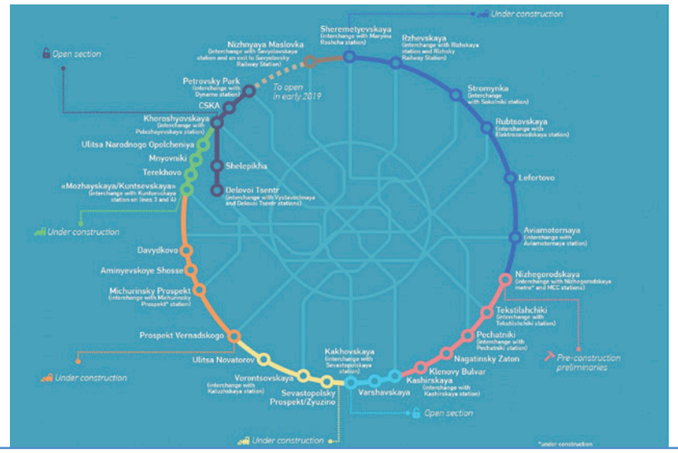
Construction of the metro started in the 1980s with two operating lines of 15.9km and 13 stations. Expansion plans will create an overall network of five lines for a total of 90.5km of track and 53 stations.

The running tunnels, between cut-and-cover stations of the existing network were excavated using Lovat TBMs imported from Canada. Collapse of the USSR in 1991 resulted in the suspension of further construction works, until the recent announcement by the Novosibirsk Regional Government to begin and complete construction of the new lines.

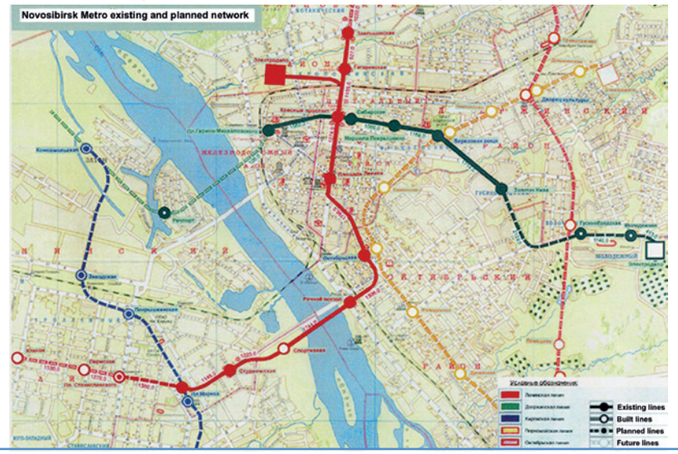
Most of the stations are sub-surface, except for the Rechnoy Vokzal, which is located partially above and below ground to connect to the Ob River bridge.

According to Mysik, the new lines will serve districts such as Levoberezhnie, which is a planned industrial dormitory district. Expansion of the metro is an acute need for Novosibirsk as its existing lines connect only six of the nine districts of the city.

According to Grigory Melnik, General Director of Novosibmetroproekt CJSC,



Left: Fig 1. Moscow Metro and planned extensions; Fig 2. 69km Moscow Circle Line



From left: Existing and planned Novosibirsk Metro; Metro bridge over the Ob River

EUROPE

while most domestic TBMs cannot compete with their foreign counterparts in terms of speed, with rates of 70m/month compared to 170m/month in the case of most of imported machines, the use of Soviet-developed machines could still be beneficial during tunnel building activities in Russia. This is mainly due to problems importing components and spare parts for foreign TBMs, given current trade sanctions.

Most of the running tunnels for the new lines, it is reported, will adopt the single tube, double track, large diameter TBM design of the so-called Madrid method, which allows for faster construction rather than using two smaller diameter machines for twin tube, single track running tunnels.

Kazan expansion

In Kazan, capital city of the Tatarstan Republic, Marat Izatullin, Director of the Main Investment and Construction Department (GISU RT), explained that expansion of the city's metro involves building a second line after the first line was completed in 2005. The first line of 16.9km long, with one station built underground, was excavated using Lovat TBMs from Canada. According to Kazan authorities, the new line might involve reuse of the 10.85m diameter single-tube double-track Herrenknecht TBM that completed its drives for the Moscow Metro extensions in 2017. ■

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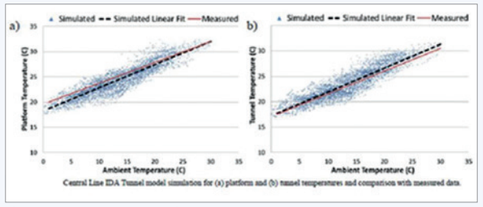
Industry Feedback

From: Calvin Barrows, Chartered Engineer, UK

I read with interest that one of the main operating problems for the Moscow Metro is related to its ventilation system which cannot cope with the increase in temperatures during the summer season. The current response to metro overheating is either to do nothing or to install plants to cool the whole of the underground network, which addresses the symptoms and not the root cause and is imprudent in terms of capital, environmental and running costs. A report on the subject by the University of Cambridge Engineering Department entitled *Thermal Modelling and Parametric Analysis of Underground Rail Systems* includes two graphs that clearly show a linear relationship between ambient temperature and temperatures underground in the tunnels and stations. This supports my hypothesis that ambient heat increase is carried into the underground environment by the trains.

There is consensus that underground space or non-operational railway tunnels in clay have a background temperature of about 14°C. However, the figures show a linear relationship between the rise in ambient temperature and the rise in tunnel and station temperatures, with platform and tunnel temperatures at 17-18°C at zero degrees ambient. Hence, if we draw lines parallel to the best fit lines, which pass through the zero ambient temperature axis at 14°C, this represents a train running using zero energy to move and stop (thus producing zero heat) but with the platform and tunnel temperatures still rising linearly with the ambient temperatures. This would suggest that all the non-seasonal heat sources are accounted for in the approximate 4°C difference between the best fit line and the parallel line passing through the zero degrees ambient axis at 14°C. This makes sense because *all* these non-seasonal heat sources are insufficient to keep the passengers warm in the winter without the use of saloon heaters.

Trains on the surface cannot jettison their absorbed heat energy during summer before entering the underground alignments. My suggestion is that while they are on the surface, we should protect them from absorbing too much irradiation by applying a sunscreen. See p24 for further information on the topic and how this could be achieved. ■



Credit: University of Cambridge Engineering Department

Russia link for China-Europe transport corridor

Eugene Gerden for *TunnelTalk*

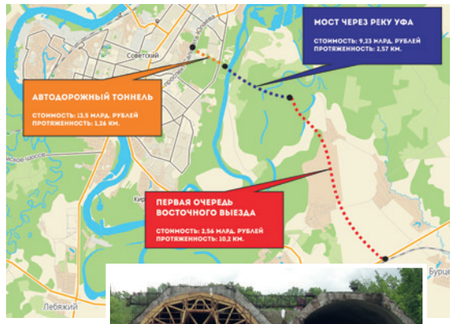
Construction work on a highway tunnel in Russia is to resume as part of new plans to complete a toll road transportation link between China and countries of the European Union. Authorities of the Republic of Bashkortostan, a Russian region located between the Volga River and the Ural Mountains, are planning to complete the Ufa road tunnel that was suspended in 2007. The tunnel is part of a project that will connect the M5 and M7 federal highways in Russia and as part of building out an exit road from the city of Ufa to the M5. In addition to completing the1.25km tunnel, the project involves 12.8km of new four-lane, dual-carriageway and a road bridge over the Ufa River (Fig 1).

The Ufa tunnel has been underway since 1995 but was suspended at the start of the global economic recession in 2007.

Works were completed to about 30% at that time, with installation of a concrete invert slab and preparations for construction of a central shaft. The technical condition of the completed sections of the tunnel remains good due to an annual investment of RUB200 million (about USD$2.7 million) by the Bashkiria Government to maintain the works since 2008.

The project is to be implemented by the Bashkir Concession Company, a financial group partially owned by the Turkish construction company Limak Group. The completion concession project is estimated at RUB20 billion. Of this, about 50% will be allocated from the Bashkiria regional budget with the remainder provided by the Russian Federal Government plus private investors, including large state banks, on a parity basis.

Fig 1. Tunnel (orange) connects to a bridge (blue) and a new highway (red)



The new tunnel will be located under a cover of 50m to 80m and is designed for both cut-and-cover and drill+blast excavation.

Earlier tunnelling works were complicated by difficult geological conditions, particularly soft ground. According to Ptitsum Gleb Ptitsun, head of the first Ufa tunnel project: "The situation is complicated by the presence of quick grounds and clays, which significantly slowed down the rate of tunnelling works." Earlier works included shaft excavation using an 8m diameter 1SPKV-8.0 shaft sinking machine.

According to local reports, the list of potential bidders for the project includes OJSC Mosmetrostroy, which may provide support to Management of Construction No. 30 to complete the works. ■

Above: Portal of the dual carriageway infrastructure
Below: 1SPKV-8.0 shaft sinking machine used on earlier Ufa tunnel works

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St Petersburg Neva River highway revival

Eugene Gerden for *TunnelTalk*

The Russian Federal Government, together with the authorities of the St Petersburg region, plans to resume building of the Orlovsky highway project. This time the project features parallel 10.3m diameter tunnels of about 2,200m long to accommodate two traffic lanes in each direction under the Neva River, rather than the single-tube double-deck tunnel of three lanes on each deck developed in 2007.

The new project, being developed by Moscow design and engineering company Metrogiprotrans, is located under the historic area of St Petersburg to provide a much-needed link under the Neva River. Renamed the Sredneokhtinsky project, it is expected to be carried out by the Moscow-based company OJSC Metrostroy.

The new tunnel is considered a cheaper alternative to the 2007 Orlovsky Tunnel initiative, which was proposed during the investment boom in St Petersburg and for which a technical concept was officially adopted. Design of a record-breaking 19m diameter TBM was also commissioned with Herrenknecht.

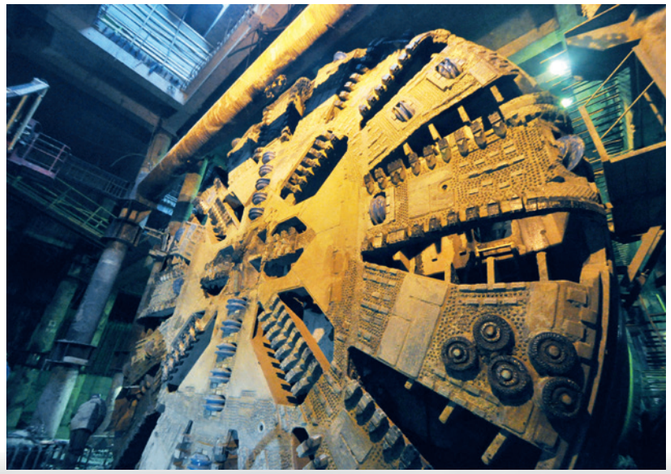
After signing an investment agreement in 2010, the cost of the 2007 project exceeded RUB80 billion (USD$1.23 billion) - two times higher than initial estimates. It was the appointment of Georgy Poltavchenko as Governor of the city that resulted in the suspension of the project as too expensive for the city's budget.

Technical concept of Orlovsky tunnel created in 2008

Arrival of Vladimir Beglov as the new St Petersburg Governor creates conditions for resuming the project, in accordance with its revised design and at a revised total cost not to exceed RUB40 billion.

The revised twin tube project will be excavated at a depth of 9m beneath the bed of the Neva using the 10.5m diameter TBM purchased by Metrostroy from Herrenknecht in 2015 for excavation of two sections of the St Petersburg Metro.

Nadezhda shield used for the St Petersburg metro



One possibility of funding the project is to include a PPP public-private partnership concept. Part of the funding could be provided by infrastructure bonds. The toll tunnel, with a fee of RUB300 (USD$4.50), will have a traffic capacity of up to 60,000 cars/day.

Experts believe there is no real alternative to the tunnel. Another option may be a high-level bridge, but this will lead to the need of building technically complex junctions, which will result in a significant increase of the costs of the project. A bridge would also have a negative effect on the world-renowned urban views of historic St Petersburg.

Most experts, however, warn of potential risks. Valery Kuznetsov, Director of the mechanization department of Metrostroy, said: "Implementation of the project will be associated with serious technical difficulties, taking into account complex ground in the bend of the Neva River and most importantly, construction of large portal structures."

The same opinion is shared by Johannis Henning, CEO of Herrenknecht Tunnelservis, a subsidiary of Herrenknecht, who worked on several applications of large diameter Herrenknecht TBMs in Moscow, including the Lefortovo highway project. He said one of the biggest challenges during tunnel works in St Petersburg is the abundance of boulders in the saturated soils and the variability of ground conditions which prevent normal operating of the shield, and potentially damage its working body. He added that the situation is aggravated by the fact that technicians and service workers cannot always determine whether repairs require hyperbaric interventions for inspection and maintenance of the TBM and cutterhead.

Implementation of the project has been welcomed by some leading Russian scientists in the field of civil construction and tunneling works. Oleg Bely, Chairman of the Council of the Russian Academy of Sciences commented: "The construction of the tunnel under the Neva will certainly improve the transport infrastructure of the city. We have underestimated the possibility of using underground space in the past." ■

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Doubling Severomuiski to add rail capacity in Russia

Eugene Gerden for *TunnelTalk*

Plans are advancing to construct a parallel tube to the existing 15.3km long single-track bi-directional Severomuiski railway tunnel to increase capacities on the Baikal-Amur Mainline (BAM) railway in Siberia. The new tunnel will increase capacity of this section of the broad gauge BAM railway line from the current 16 million to 100 million tonne of cargo/year and make Russia a new transit hub for the delivery of Asian Pacific cargo to the European Union. The investment will double the carrying capacity of the BAM rail service to up to 30 trains/day by 2030, compared to its current 12-15 trains/day.

The lack of a second track of the tunnel makes it a bottleneck of the entire BAM, according to Oleg Belozerov, head of the Russian railway monopoly RZD.

Both local State-owned corporations and private investors have shown interest in contributing to the funding of the new tunnel. The leading private partner in the proposed PPP public private partnership model is the Sibanthracite Group which has ambitious plans to increase its annual coal cargo transportations by up to 50 million tonnes on both the BAM and Trans-Siberian railways. The company, owned by millionaire Dmitry Bosov, is ready to invest up to RUB 100 billion (USD$1.5 billion) to build the new tunnel.

According to Andrei Makarov, the Deputy Director General of RZD, a feasibility study has been presented to the Russian Government for the tunnel to be built by 2026-2027 at an investment of about RUB120 billion (USD$2 billion).

RZD experts consider it a high possibility that the project may face the same complex geological difficulties that occurred during the building of the first tunnel, particularly with the prevalence of thermokarst and permafrost. Construction of the first Severomuiski tunnel began in 1975 and its official commissioning took place in 2003.

Implementation of the project may be complicated also by high seismic activity in this area and by the watershed between Lake Baikal and the Vitim River, which is located in close proximity to the planned construction site. Radiation may be another problem as the site of the future tunnel is characterized by high concentrations of radon.

To minimize risks, there are plans to advance an exploratory/drainage gallery to evaluate geological conditions, drain water ingress and improve ventilation during excavation. The drainage gallery will also provide access for opening additional faces for main tunnel advance. Excavation of the new tunnel is expected to advance from both portals and in both directions from two intermediate shafts of up to 300m deep. ■

Existing single-tube, single-track, bi-directional Severomuiski tunnel

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A Robbins return to Siberia

Desiree Willis, Technical Writer, The Robbins Company

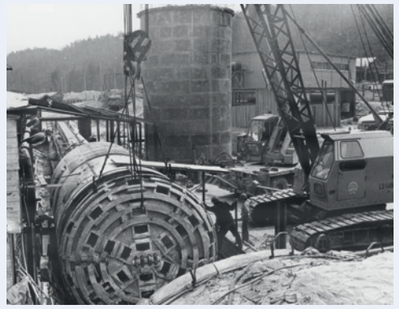
Forty years after supplying a 4.56m diameter double shield machine to help bore the service tunnel of the first Severomuiski project, the Robbins Company has an order for two new 10.37m diameter Crossover XRE TBMs to work on the main parallel tunnel. The new 15.5km long tunnel will pass through mixed ground and fault zones that caused major geotechnical delays and troubles during excavation of the first tunnel.

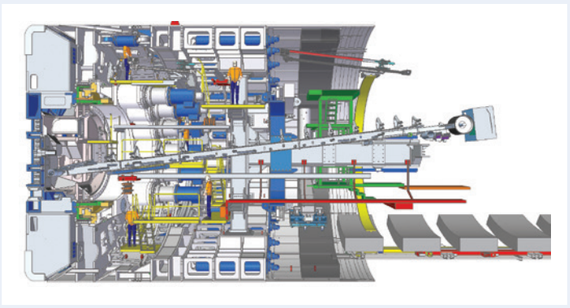
Lessons learned during the first Severomuiski experience, among them the importance of probe drilling, consolidation grouting, and preventing a shield machine from becoming stuck in fault zones or squeezing ground, are all part of the Crossover TBM solution. "Per the contract the Robbins Crossover TBMs are designed to bore in highly variable ground conditions while maintaining good advance rates." said Robbins President Lok Home, who was a young engineer working with Robbins when a double shield TBM was delivered for the first tunnel in 1979. "The XRE machines are able to operate in open mode in hard rock formations, and closed EPB mode in unstable water-logged soils."

The machines will be designed for varying water pressures from 5 to 20 bar. They will feature water inflow control, a system that seals off the face and periphery and creates a safe working environment in which to dewater and consolidate ground. The machines will feature probe drill ports and capabilities for 360-degree probe drilling and grouting ahead of the excavation face, while the Robbins torque-shift system will enable the machines to bore through collapsing ground and other situations that demand high torque. The machines will also be designed with a belt conveyor in hard rock mode that can be switched out with a screw conveyor to better handle excavation conditions in soft ground.

Other aspects of the supply include a continuous conveyor for muck removal, rolling stock, spare parts, and cutting tools. Construction of the new tunnel is expected to begin in 2020 and take five years. ■

From left: Original 4.56m double shield supplied for the Severomuyski service tunnel in 1979
New XRE TBMs will have a belt conveyor and a switch-out screw conveyor for challenging conditions





Appeal lodged after jury finds for SR99 Client

Shani Wallis, *TunnelTalk*

After losing its claim for USD$330 million to recover costs associated with the TBM breakdown and the two-year delay in completing the SR99 highway replacement tunnel in Seattle, Tutor Perini, as a 45% shareholder in the Seattle Tunnel Partnership (STP) JV with Dragados of Spain, filed an appeal. In losing its case, STP was also charged to pay a counterclaim of USD$57.2 million in damages to the Washington State Department of Transportation (WSDOT) as the Client.

In a verdict handed down in December 2019, the jury of 12 citizens dismissed the STP claim that it was the encounter with an alleged inaccurately documented groundwater investigation well casing in the alignment of the tunnel that caused failure in December 2013 of the 57ft (17.4m) diameter EPBM, the largest ever TBM at the time. The two-year delay and claimed USD$330 million in costs were incurred to construct an emergency recovery shaft to lift the cutterhead and drive unit of the machine to the surface for extensive repairs.

STP, as the fix-price design-build contractor of the USD$1.44 billion highway tunnel contract, claimed that as the TBM cut through the well casing, pieces of the 160ft long, 8in diameter x 1/4in thick steel of the test well pipe damaged vital mechanical components including the main bearing seal. The steel casing of the test well was installed during preliminary ground investigations before award of contract and had not been removed ahead of launching the machine.

During the two-year repair process, machine manufacturer Hitachi Zosen of Japan, supplied a replacement main bearing and provided engineers to work with STP crews to repair the machine for a relaunch in January 2016. From the breakdown point and recovery shaft at about 1,000ft (300m) into the 9,000ft (2.7km) tunnel alignment, the repaired TBM and its STP operating crews and management team completed the remaining 8,000ft (2.4km) of the drive. Breakthrough after passing under the operating highway viaduct and beneath the streets of central Seattle was achieved without further incident in April 2018. The double-deck, single-bore highway tunnel opened to traffic in February 2019 and today carries up to 80,000 vehicles/day, including heavy freight truck traffic.

Court documents report that STP filed a claim for $150 million when the machine encountered the well casing in late December 2013. This increased to more than $600 million as the scale of the TBM recovery progressed. The claim was reduced to $330 million at the start of the court hearing in October 2019.

During the trial, the jury heard testimony from members of senior management and engineers on behalf of both STP and WSDOT and from a number of expert witnesses called by the lawyers acting for each party. During the trial, it was discovered that pieces of the well casing pipe, retained at the time as evidence, along with large boulders removed from the TBM excavation chamber, had been discarded during site clearance at the end of the project. Also missing were STP engineering journals that documented the details of encountering the pipe casing and the days following, before the machine was stopped and needing repair.

In a statement after the trial, the Governor of Washington State, Jay Inslee, said: "We never wavered from our position that it was always the contractor's responsibility to fix the tunneling machine and that taxpayers should not pay the repair bill." In lodging its appeal, Tutor Perini stated that the verdict conflicts with the findings of the contract's Dispute Review Board (DRB) which stated that the steel pipe casing constituted a differing site condition. Under the terms of the contract, findings by the DRB were non-binding.

In a separate case, STP is pursuing claims against the contract insurers who rejected claims to cover the TBM repairs. In a counter case the insurance providers are said to be taking action against STP for lodging a false claim.

A court case was also being prepared by Hitachi Zosen to claim final payments of about $25 million that STP had withheld for supply of the $80 million TBM. In an agreement with STP, Hitachi Zosen covered the costs of the mechanical repair of the machine and STP paid to construct the recovery shaft. Reports suggest that Hitachi Zosen and STP came to an undisclosed out of court settlement in early 2020.

With an appeal in response to this first ruling in actions taken as a result of the TBM breakdown and repair, and the resulting delays to completing the project, it is likely to take years yet to settle all disputes and claims.

In the meantime, the project was completed, by the same parties involved from the beginning. After eight years of construction and a $3.4 billion public investment, the waterfront of Seattle is now forever transformed following demolition of the elevated highway viaduct and with traffic now routed through the city's new underground highway.

Since it opened on 4 February 2019, the State highway SR99 tunnel has excelled. However, toll charges, ranging from $1 to $2.25, imposed in November 2019, have sent more than a quarter of those drivers back to surface streets, undermining the role of the tunnel. Tolls were demanded by State lawmakers outside Seattle to finalise a political deal in 2009 to adopt the bored tunnel option for the SR99 viaduct replacement. ■

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Top from left: Alleged culprit of the TBM damage and breakdown; Claims were to cover costs of the recovery shaft and repair of the stricken TBM; Repair included fitting a replacement main bearing; Below: Replacement highway route under the streets of downtown Seattle; Seattle waterfront before and after the elevated highway viaduct demolition





Industry Feedback

From: Dr Peter J Tarkoy
Is it possible that the contractor losing the court case might be attributed to a poor presentation of their position?

From: Nick Barton
On the face of it, this seems like a tough decision against the consortium STP. They have my sympathy. They did not deserve this. Nor did the Owner of course, but whose fault was it? Hardly that of the consortium.

From: A UK reader
The logic behind the decision is astounding. Although DRB decisions are non-binding, they are nevertheless the combined opinions of three knowledgeable experts who understand the contract. What is more, the DRB is appointed mutually by the Owner and the Contractor and either party needs to have good reason for not accepting a DRB decision. What is really amazing is that a jury of citizens, with no technical or contractual experience, should contradict the unbiased verdict of three experts.

From: A UK reader
I like your report on Seattle contract. Feel more than a bit sorry for the contractors particularly as the DRB found otherwise, and the contractors seems to have done a lot to save overall delays to the project by construction of the interior structures and road decks concurrent with operation of the TBM.

From: Chris Pressdee
I find it unbelievable that they discarded the steel casing and journals from the encounter with the well. ■

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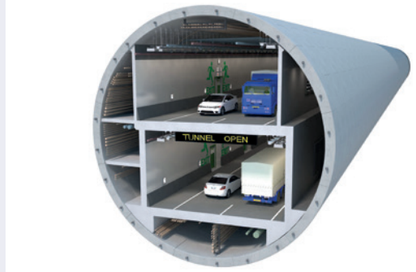
Design of the new double-deck underground highway; The 17.4m diameter EPBM, one of the largest ever



California High-Speed Rail

State Route 180 Fresno Trench underpass

Karen Martin, *TunnelTalk*

Projected at USD$77 billion, the high-speed rail service from Los Angeles to San Francisco hit another barrier after recording delays and rising costs. In May 2019, the White House administration terminated the $929 million grant of Federal funding to the California High-Speed Rail Authority (HSRA), declaring that it had failed to make reasonable progress on the project.

In response, California filed a Federal court lawsuit, claiming the USA Transportation Department lacks authority to withhold the grant. The Federal Railroad Administration (FRA) agreed not to redirect the funds to another project while the dispute progresses.

The decision follows announcement by California Governor Gavin Newsom in February 2019 of a substantially scaled-back plan for the project. "There is no doubt that our State economy and quality of life depends on improving transportation," said Newsom, "but the current project, as planned, would cost too much and take too long." He confirmed that the 119 mile (191km) section under construction between Merced and Bakersfield in the Central Valley will be completed. "The Central Valley endures the worst air pollution in America and some of the longest commutes," he said. "They deserve better and the high-speed rail project will be part of that."

In 2008, voters were told the project would cost $45 billion. The actual cost now appears closer to $80 billion. The Federal Government decided that the project should begin in the Central Valley nearly a decade ago when it deemed that segment worthy of Federal funding. The Authority believes that delivering this first working section will demonstrate the viability of the broader project and attract other funding to complete the line north and south.

Construction continues in the Central Valley at more than 24 active sites. The Fresno trench, north of downtown Fresno, in Construction Package 1, is about 1 mile long and is up to 40ft (12m) deep. It runs parallel to Union Pacific freight rail tracks and will carry high-speed trains under State Route 180, a rail spur, and an irrigation canal, and includes a barrier wall to separate high-speed and freight trains.

Statewide map of the phased high-speed rail implementation

Additional project development includes the environmental clearance for all San Francisco to Anaheim project segments by 2022 and targeted bookend investments in the Bay Area and Los Angeles.

Recent cost estimates for the Bakersfield-Fresno-Merced section and the Phase I San Francisco to Anaheim environmental clearance, stand at $20.4 billion, with the acknowledgement that costs could rise with unpredictable developments.

The tunneling aspects of future sections of the project are among the most challenging elements of the system. The Authority intends to create a specially selected tunnel delivery advisory panel to help identify the areas of greatest risk. The panel will focus initially on the northern Pacheco Pass tunnels in Phase I, and consult industry tunneling experts, including contractors, TBM manufacturers, engineering firms, geotechnical engineering firms and firms specialising in tunnel construction and risk management.

The main cost categories driving the estimates for the Pacheco Pass tunnel are procuring tunnelling equipment, mining and mucking operations, pre-cast concrete lining production, and time-dependent indirect costs. Pacheco Pass cost estimates are said to be in line with historic costs of rail transit and commuter rail projects in the USA. The Early Train Operator, however, has recommended that HSRA perform supplemental geotechnical investigations and review the tunnel design criteria to potentially reduce overly conservative construction cost estimates commonly associated with the unidentified risks of underground construction. ■

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Narragansett Pawtucket CSO project shortlist

Shani Wallis, *TunnelTalk*

From 10 prequalified groups, three of those shortlisted are preparing fixed-price design-build proposals due in May or June 2020 for the Phase III Pawtucket tunnel of the Narragansett Bay Commission CSO project in Rhode Island: The prequalified shortlisted bidders are:

- Cardi-Obayashi-McMillen Jacobs
- CBNA (Bouygues)-Barletta-AECOM
- Lane Construction-Brierley Associates

Stantec, and partner Pare Corporation, is Program Manager for the project.

As the third and final phase of the Narragansett Bay CSO program, the new tunnel in the city of Pawtucket will run 11,600ft (3.5km) adjacent to the Blackstone River to provide 58.6 million gallons of storage and direct combined flow to the Bucklin Point wastewater treatment facility in East Providence. The 30ft (9m) i.d. rock tunnel will be excavated by TBM at up to 180ft (55m) deep and is designed with a gasketed, precast segmental lining. The one pass segmental lining, as opposed to two pass systems used on previous phases of the program, is said to be selected as the best suited to controlling groundwater inflows, maintaining rock stability, ensuring long-term quality and reducing construction time.

The contract scope includes two working shafts for TBM launching and reception; four drop shafts of 6-8ft i.d. x 145-175ft deep (1.8-2.5m x 45-55m) and a pump station cavern of 62ft wide x 70ft high x 120ft long (20m x 22m x 36.5m).

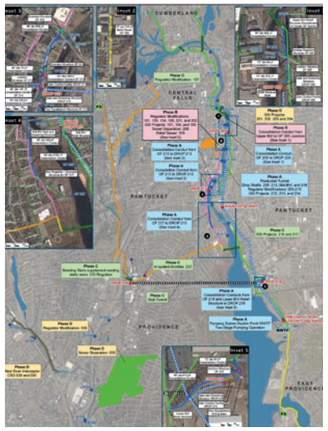

Fig 1. Refined Phase III project

The CSO control program for the city of Providence and the surrounding areas began in 1992. The main element of the $360 million Phase 1 project, completed in 2008, was excavation of a deep rock storage tunnel and large pumping station cavern in Providence to store combined flows for pump out at the Field's Point treatment plant. The USD$197 million Phase II programme, started in 2011 and completed in 2015, consisted of a network of interceptor tunnels to connect additional outfalls to the Providence tunnel.

Before embarking on Phase III, the Narragansett Bay Commission engaged a team of engineers, led by MWH (now part of Stantec) and Pare Corporation (NBC), to study the use of green stormwater infrastructure alternatives. The optimized Phase III plan is a four-phase implementation schedule that continues to be centred on the Pawtucket tunnel as Phase IIIA (Fig 1). Phase IIIB includes design and construction of additional interceptors and Phase IIIC is design and construction of a deep rock stub tunnel under the Providence River to the east side. Phase IIID as the final phase addresses the remaining outfalls in the Field's Point service area and includes the West River and Branch Avenue interceptor tunnels (Fig 1).

Phase IIIA is programmed to reach substantial completion by December 2024. ■

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Geology challenges Texas interceptor

Robbins News Release

Claimed to be the longest hard rock tunnel ever bored by a double shield TBM with a diameter of less than 2.5m, the 3.5km Parmer Lane wastewater interceptor in Austin, Texas, has been completed by contractor SJ Louis Construction. The drive included two tight curves of 150m radius and unexpected ground conditions that required modification of the cutterhead inside the tunnel. Maximum advance was 380m/month, working in single 12 hour shifts/day.

The interceptor connects two existing lift stations allowing them to be decommissioned and adds gravity flow capacity to reduce operating costs for the City of Austin.

While moderately hard limestone, and an occasional thin seam of clay or soft material was expected, the first 1.2km was in a softer, saturated dolomite material with clay. The remainder was in the expected limestone formation. For the softer rock, two double disc cutters were added by TBM manufacturer Robbins at positions 10 and 12, and the single disc cutter was removed at position 11. This added another transition cutter and helped with muck flow through the cutterhead. Robbins assisted the crew with tight curves.

"While we excavated through the softer material, our best advance was close to 0.9m/hr. When we bored through the expected limestone, advance rates were more than 5.2m/hr. Our best day was 25m in a single shift," said Zach West, Project Manager for SJ Louis. "The 2 mile drive in a small tunnel with tight radius curves and limited surface access was difficult," he added. The shallow depth and the alignment to within a few feet of sanitary lines, high-pressure gas mains, and fuel tanks for gas stations, made TBM guidance critical. "We guided the machine successfully through these obstacles and into our retrieval shaft within our expected tolerances."

End of the record-breaking run

Through one stretch, the TBM advanced directly between a 30cm diameter, high-pressure gas main and fuel tanks for a gas station with limited as-built information. "Navigating this section took a great deal of coordination with the local utility companies. Because the diameter was too small for an automated guidance system, we manually surveyed the front of the machine at every push to ensure the machine was on track," said West.

The majority of the route used a simple two-rock-bolt pattern for support. In the last 10%, ribs and lagging were used. The tunnel is finished with an internal 110cm diameter fiberglass pipe.

The project is part of a trend towards small diameter, TBM-driven rock tunnels in the USA, explained Tom Fuerst, Robbins Utility Tunneling Sales Manager. "Because of demographics and business growth, there is a growing need to increase sewer and water infrastructure. TBMs can excavate long distances with tight curves, reducing the need for multiple shafts, which lowers the overall project cost. As most small diameter pipelines follow a road or municipal right-of-way, traffic problems are reduced significantly compared with open cut operations." ■

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CSO solution goes underground in Louisville

Jonathan Rowland, *TunnelTalk*

Fig 1. The 2.5 mile route cuts under the Ohio River and eliminates four storage basins

Waterway protection went underground in Louisville, Kentucky, after challenges to the construction of four surface CSO storage basins saw the project adopt a 5 mile storage tunnel for similar cost, while providing greater capacity for less surface disturbance. With excavation underway, the project should be completed by the end of 2020 to meet a Consent Decree mandated operating date of Spring 2021.

Jacob Mathis, Project Manager for the Louisville Metropolitan Sewer District (MSD), told *TunnelTalk* of various obstacles to the storage basins including the availability of suitable land, the impact of construction on the area, and opposition to surface storage basins from the owners of adjacent real estate. "We worked with our engineer of record, Black & Veatch, and came up with the waterway protection tunnel. This ultimately extended beyond the original scope to eliminate all four remaining storage basins."

Design had to be completed quickly to allow construction to begin on schedule. "A project like this would normally take at least 18 to 24 months to design," said Mathis. "We accelerated this to eight months with permitting concluded quickly by Federal and State agencies.

The original underground alignment was designed to be 2.5 miles long x 22ft o.d. (4km x 6.7m), providing a storage capacity of 37 million gallons (140,060m³). The subsequent extension brought the length to 4 miles (6.5km) with a capacity of 55 million gallons (208,197m³) (Fig 1).

About a mile of the alignment lies under the Ohio River. The route runs at up to 185ft-215ft (56m-65.5m) deep at a 0.2% grade. The geology comprises an overburden of manmade fill, alluvium and glacial deposits over a shale, limestone and dolomite bedrock. A refurbished Robbins main-beam TBM was launched in January 2019 by the engaged Shea Traylor JV.

During excavation of the 1,200ft (365m) bifurcation that comes about 966ft (295m) into the alignment, crown spalling slowed progress of the TBM. "Because the TBM had to be backed-up along the bifurcation, a roof support had to be recessed into the crown along the whole bifurcation zone," said Alston Noronha for the Black & Veatch Construction Management team.

In addition to the TBM drive, the project includes eight shafts. The larger diameter shafts are secant pile structures through the overburden, followed by drill+blast through the bedrock, while the 33ft (10m) diameter reception shaft is a steel ribs and liner plate process through the overburden followed by drill+blast. The remaining smaller diameter shafts are steel casings driven through the overburden, followed by raise boring. Except for the final drop shaft, for TBM reception, the drop shafts are offset with drill+blast connecting adits to the main alignment.

Work on the 48ft (14m) o.d. pump station shaft is complete and it has been turned over to Pace Contracting for installation of the ten 3,500 gal/min submersible pumps and two 1,000 gal/min grit pumps.

The waterway protection project forms part of the Consent Decree agreement between Louisville/Jefferson County MSD and the USA Department of Justice, the Federal Environmental Protection Agency, and the Kentucky Division of Water to comply with the Federal Clean Waters Act of 1972.

The USD$147 million contract, with the Shea Traylor JV, is equivalent to that of the storage basins it replaces, while offering lower operating and maintenance costs in the long run. ■

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One TBM for two-diameter Dallas alignment

Jonathan Rowland for *TunnelTalk*

A Robbins TBM designed to down-size from 37.5ft to 32.5ft (11.6m to 9.9m) diameter midway through excavation will be used for the 5 mile (8km) Mill Creek drainage relief project in Dallas, Texas. The change-over will be implemented underground and allows the project to utilise one machine for the entire alignment.

The upstream 3.24 miles (5.2km) is designed for a peak flow of 15,000ft^3/sec while the downstream 1.76 miles (2.8km) was designed originally with a horseshoe cross section for a higher peak flow of 20,000ft^3/sec (Fig 1). The horseshoe section was to have been excavated by the TBM initially and expanded by roadheader with two different sets of formwork to cast the final lining for both profiles. This would have been time consuming and costly.

As a result, Robbins developed the adaptable TBM that could transition from the larger to the smaller diameter, underground. Spacers on the cutterhead can be removed and the bucket lips adjusted to convert to the smaller diameter (Fig 2).

The larger 38.1ft (11.6m) diameter of the main beam gripper TBM is claimed as the largest hard rock TBM to work in the USA. Contractor Southland/Mole JV will make the conversion in a process expected to take six to eight weeks. The outer wraps on the gripper shoes, cutterhead support side stabilisers, and the upper shield sections will be removed, followed by the outer cutterhead segments and cutterhead spacers for the outer segments to be re-bolted directly onto the centre section.

The outer cutterhead segments and cutterhead spacers will be retrieved to the surface through an intake lateral located in the transition area. Lifting points have been pre-designed and the parts made in a modular fashion, so that simple lifting gear and jacks can be used to make the conversion in the tunnel. The TBM will then continue the excavation, beginning with a 2% uphill bore until the crown is aligned. The crown will then be smoothed after the TBM has advanced.

At depths between 100ft-150ft, the route passes through Austin Chalk with the potential of encountering natural gasses. As a result, probe drilling is mandatory.

Ground support, comprising eight 13ft long rock bolts on 5ft centres with wire mesh and channel straps, is expected to be required in some areas and the drainage infrastructure will be finished with a 380mm thick cast-in-place concrete lining. MSP Structures is suppling a telescopic shutter for the final lining, which is capable of changing in diameter in the transition area to cast the lining in both cross sections.

TBM excavation is expected to progress at about 80ft (25m)/day, allowing the project to be completed on time in 2023. Muck haulage will be by a continuous conveyor supplied by Robbins and designed with special idlers to allow for banking around the 60% radius curves on the route. A specific muck removal shaft has been sunk to allow round-the-clock hauling operations.

In addition to the outfall and muck removal shafts, there are five intake shafts of 14ft to 20ft and 47ft for the outfall shaft. With a ban on blasting within the city, shaft excavation is by excavators and hydraulic breakers. All intake shafts are offline with laterals constructed by roadheader and excavator. The 170ft (51.8m) deep pump station is located at the point where the diameter of the alignment changes and will house three 10,000-12,000 gal/day submersible pumps to dewater the tunnel during maintenance. During normal operation, the system is designed to be gravity driven, functioning as an inverted syphon. ■

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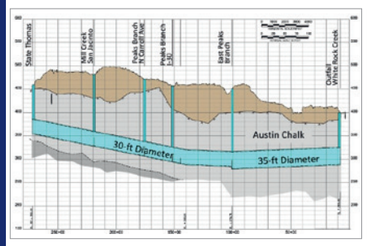

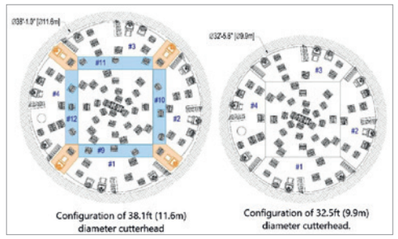

From left: Fig 1. One tunnel, two diameters, through the Austin Chalk; Fig 2. Arrangement for cutterhead change; TBM ready for launch

Delaware aqueduct bypass breakthrough

DEP News Release

Excavation of the Delaware Aqueduct Bypass under New York State concluded in August 2019. The breakthrough for the Kiewitt-Shea and CM Parsons JV and the New York Department of Environmental Protection (DEP) was achieved on budget and ahead of schedule. The USD$1 billion effort to repair water leaks in the aqueduct, which conveys about half of the daily drinking water needs of New York City from reservoirs in the Catskills, is the largest repair project in the 177-year history of the New York City water supply system. When complete, the 2.5mile (4km) bypass tunnel, 600ft (183m) under the Hudson River, will connect to structurally sound portions of the existing aqueduct on either side of the river.

Excavation was undertaken by a Robbins 6.8m diameter TBM which completed the drive in 582 days. The machine was built to withstand more than 30 bar of groundwater pressure, believed to be the most of any TBM ever manufactured. As high-pressure inflows were encountered when the aqueduct was built, the machine was equipped with pumping equipment rated at 2,500 gallons of water/min.

The TBM cut through three bedrock formations and lined the tunnel with 2,488 rings of segments. DEP will now install 230 16ft (4.9m) diameter steel liners, before coating with a second layer of concrete to provide structural stability and prevent leaks.

DEP has monitored two leaking sections of the aqueduct since the early 1990s. The leaks release about 20 million gallons/day with 95% of that escaping near the Hudson River in Newburgh. In 2010, the City announced a plan to repair the aqueduct by building a bypass around the leaking section in Newburgh and grouting the smaller leaks in Wawarsing. The project began in 2013 with the excavation of two vertical shafts that were completed in 2017.

When work is nearly complete, the existing tunnel will be taken out of service and work will begin to connect the bypass and perform the repairs in Wawarsing. The project will mark the first time that the aqueduct will be drained since 1958. In 2013, DEP installed new pumps ahead of draining the tunnel in 2022. The nine pumps can remove a maximum of 80 million gal/day. The largest of the pumps are 23ft (7m) tall vertical turbine pumps that each weigh 9 tonne. ■

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Breakthrough of bypass drive

DigIndy TBM more than halfway along 45km route

Jonathan Rowland, *TunnelTalk*

Mining of the 6.1km Fall Creek section of the DigIndy deep-level CSO storage tunnel under Indianapolis will follow completion of excavation on the White River route, according to Mike Miller, Construction Manager for owner, Citizens Energy Group. About 27km of the 45km network has now been excavated by the refurbished Robbins TBM previously used on the Second Avenue Subway in New York City. The project is on target to meet its Federally-mandated completion date of 2025.

DigIndy comprises six alignments. The 12.2km Deep Rock Tunnel Connector, DRTC, and 2.7km Eagle Creek elements have been operational since December 2017, so far capturing 1.5 billion gallons of CSO. Mining is also complete on the 9.3km White River and 2.9km Lower Pogues Run sections with lining work and adit/deaeration chamber construction now underway on both.

Fall Creek will be the penultimate excavation, after which the TBM will be refurbished and set to bore the 11.8km Pleasant Run alignment by contractor Shea-Kiewit JV. The route is bored at 6.2m diameter and finished at a depth of 76.2m with a 30cm cast-in-place concrete lining. The system will capture CSO from most of the 134 outflows in the city, holding about 250 million gallons at any one time and preventing about 6 billion gal/year of CSO flowing into the river.

Drive strategy

The project is being excavated by one TBM and requires only eight large-diameter shafts, thanks to a drive strategy that has seen the machine mine three bifurcations to the main DTRC-White River-Fall Creek alignment, before backing up and continuing (Fig 1).

After mining the DRTC, the contractor proposed mining Eagle Creek, originally a shallow alignment, as a deep-level spur to the DRTC. This saved time and reduced surface disruption while adding about 17 million gallons of storage capacity. The contractor backed the TBM down the DRTC, excavated Eagle Creek, then backed up again and walked the TBM to the end of the DRTC, avoiding the need for a retrieval shaft, to begin mining on White River drive in 2016.

The TBM is currently about 274m into the Fall Creek alignment. When it reaches the end of Fall Creek, which Miller expects relatively quickly due to favourable geology, the TBM will be retrieved and refurbished for the Pleasant Run drive, which Miller expects to begin later in 2020.

Large diameter shafts are located at the Southport launch site, at the end of the DTRC, at the White River-Fall Creek boundary, and at the end of Fall Creek, as well as at the launch site, halfway up and about 914m from the end of Pleasant Run. "We were not able to put a large-diameter shaft where Pleasant Run terminates, so we have to mine to the end of the alignment and then back the TBM up to the retrieval shaft," said Miller.

Groundwater infiltration

The geology has been fairly consistently limestone/dolomite bedrock, with some sections of higher groundwater infiltration. As a risk mitigation measure, the owner and contractor worked together to develop a strategy for probing ahead. If infiltration above a certain tolerance is encountered, the owner pays for the additional time and materials needed to resolve the issue. "This shared risk approach provides value to the owner based on expected levels of groundwater infiltration, and protects the contractor should higher levels be encountered," said Miller.

From top: Breakthrough on White River section; Crane-mounted oscillator installs drop shaft cans

Pump station

The project includes a new underground pump station at the Southport treatment facility. Constructed by the Oscar Renda-Southland JV, it includes a 30m long x 18m wide x 23m high cavern to house four 30 million gal/day pumps. The cavern was constructed by drill+blast and is supported by 700 rock bolts. A waterproof membrane and shotcrete finishes the cavern. The pump station is connected by a 1.8m diameter x 55m long tunnel to the original launch shaft, which now functions as the screen and grit shaft.

Managing ventilation was challenged by the various bifurcations along the route, explained Miller. "We do not want air from the mainline to enter the smaller runs because we only have a small diameter shaft at the end of those. So we built 1.5m diameter bulkheads from the crown to redirect any air and make sure it vents at the launch or retrieval shafts."

Shaft construction

The 33 drop shafts along the route bring surface discharges to the tunnel alignment with limited air entrainment. With the exception of those at the dead ends, these drop down into deaeration chambers that are connected to the mainline through adits. The adits and deaeration chambers are constructed by drill+blast, while the drop shafts are primarily excavated by raise boring through the bedrock and by an oscillation excavation method through the overburden. A crane-mounted rig takes a 3cm thick x 3.7m diameter can and oscillates it through the overburden using a specialised clam bucket. Two 30m-33m shafts can be installed in less than two weeks.

The efficiency of this system and its rarity, with only one or two in the USA, prompted DigIndy to construct all the drop shaft overburden excavations at once, including those adjacent to sections that had not yet been excavated. "We have put all of the cans in for the remainder of the program," said Miller, completing the final one in late August 2019.

"DigIndy is one of the largest civil works projects in Indianapolis history," said Jeffrey Harrison, President and CEO of Citizens Energy Group. "Employees work hard every day to find innovative ways to keep DigIndy on schedule and below budget, and highly skilled contracting partners continue to provide effective solutions to complex issues. The DigIndy system is going to help restore water quality in local waterways to levels not seen in more than 100 years and improve the quality of life for central Indiana." ■

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Fig 1. Six sections of the DigIndy CSO system

Las Vegas people mover build begins

TunnelTalk reporting

A USD$52.5 million underground people mover for the Las Vegas Convention Centre began as the first commercial contract for The Boring Company, founded by Elon Musk. With three underground stations, the twin tunnels of about one mile (1.6km) each will connect the existing 3.2 million ft² (297,000m²) of convention space with the new 1.4 million ft² (130,000m²) West Hall currently under construction. The project is part of a $1.52 billion expansion and renovation project at the conference campus.

A refurbished Lovat TBM and a segmental lining system, used on the first excavation effort by the company in Los Angeles, is used again for the people mover. The machine launched in November 2019. to operate at about 12m below ground and progress at 100ft (30.5m)/day.

When completed, scheduled for January 2021, electric Tesla vehicles will carry up to 16 people/vehicle across the 200-acre campus in 1 minute. The system is designed for a ridership of at least 4,400 passengers/hr and is scalable depending on convention attendance.

At the TBM launch, Steve Hill, CEO of the Las Vegas Convention and Visitors Authority, said that the system has the potential to expand and link Las Vegas attractions including the Las Vegas Strip, and McCarran International Airport. ■

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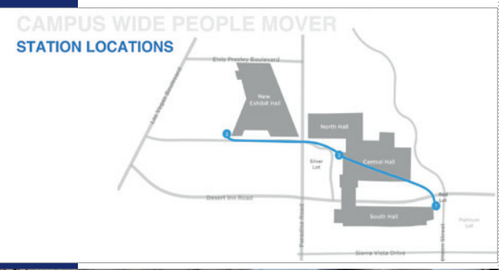

TBM ready for launch

Budget trimmed to advance Hudson Gateway

Patrick Reynolds for *TunnelTalk*

A major cost reduction was submitted in a revised 2019 budget for the long-awaited New York-New Jersey Gateway Hudson River underpass. The cuts reduce the budget of the tunnel works to USD$9.5 billion from previous estimates of $11.1 billion. Overall cost of the project is reduced to $11.3 billion from estimates of $12.7 billion according to project delivery group the Gateway Program Development Corporation (GDC).

Reductions were secured through extra design, fewer contract lots, wider procurement options, including design-build, and a risk and value-for-money analysis. GDC is working in partnership with Amtrak, New Jersey Transit, the New York and New Jersey Port Authority, and the administration of both State Governments.

In addition to the twin rail tunnels under the Hudson River, underground infrastructure includes a short concrete portal in the Hudson Yards development site on the west side of Manhattan and rehabilitation of the existing twin-tube North River rail link under the Hudson into the Pennsylvania Station terminus in Manhattan. The Hudson Yards works were completed in early stage works and are awaiting environmental clearance.

While much of the cost will be met locally, the project is seeking a contribution of $4.36 billion from the Federal Transit Administration (FTA), down from an earlier request for $5.65 billion.

Before sign-off of funding sources, GDC plans to seek an early systems work agreement to start tunnel boring ahead of receiving a full funding grant agreement from the FTA. This would save time and cost, and give momentum to the long-delayed project.

GDC reports that design is at a point where contract tendering can begin towards a start of major construction work. Depending on Federal approval of the environmental impact statement, notice-to-proceed may come by early 2021.

Long wanted, the rail project between New York and New Jersey stalled 10 years ago when the Access to the Region's Core (ARC) initiative was cancelled. Since then, the North River rail link under the Hudson, opened in 1910, has deteriorated further, having suffered significant flood damage caused by the 2012 superstorm Sandy. Rehabilitation of the existing tunnels is planned to follow completion of the first of the new twin bored tunnel when each of the old tunnels can be taken off-line consecutively to complete the works.

The Port Authority is providing $2.7 billion for the new twin tube under-river tunnel as part of a total local contribution by the States and local authorities of $5.55 billion. Additional funding of $1.28 billion is committed by Amtrak, the rail passenger service operator for the USA which runs interstate rail services through the existing Hudson River rail tunnels into Penn Station terminus in Manhattan. This is an increase of more than $600 million from earlier contribution commitments by Amtrak, which, together with overall project cost reductions, allowed the project to request less Federal funding.

The GDC project partners undertook the financial review after a disappointing medium-low rating from FTA, due primarily to concerns about costs and certainty of local funding contributions. A team of the WSP, Aecom and STV consultancies is engaged as The Gateway Trans-Hudson Partnership in assisting GDC to push the project through planning and construction design. ■

From top: Early alignment excavations in Manhattan; Existing Hudson River rail tunnels need urgent rehabilitation

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Fig 1. Alignment of Gateway Hudson River underpass

Final breakthrough at Emisor Oriente in Mexico

Desiree Willis, Technical Writer, The Robbins Company

The last of six 8.93m (29.3ft) diameter EPBMs completed excavation of the Mexico City Túnel Emisor Oriente (TEO) conduit that revamps wastewater treatment for more than 21.2 million people in Mexico City. After ten years and 62.1km of tunneling, the final breakthrough on 23 May 2019 completed Lot 4 of the urgently needed wastewater tunnel that spanned some of the most difficult geology ever encountered by EPBMs. The 10km long Lot 4, at depths of up to 85m, included sections of basalt rock interspersed with permeable sands under high water pressure. "Our machines had to go through the worst geology, but they were designed for it," said Roberto González, General Manager for Robbins Mexico. Three Robbins EPBMs with continuous conveyor muck haulage systems were used on Lots 3, 4, and 5 of the project.

The TBMs were designed for water pressures from 4 to 6 bar, with mixed-ground back-loading cutterheads equipped for variable ground conditions. High pressure tungsten carbide knife bits could be interchanged with 17in diameter carbide disc cutters depending on the geology.

Despite multiple challenges, the Lot 4 EPBM operation achieved a project record of 30m in one day, and a high of 528m in one month, assisted by the continuous conveyor muck removal system.

"We solved challenges, including large inflows of water, hydraulic loads and constant changes in geology, by adapting the excavation mode according to each type of geology found," said Hector Arturo Carrillo, Machinery Manager for Lot 4 contractor CARSO. The Lot 4 TBM was assembled in launch shaft 17 and commissioned in August 2012, with the bridge and all the back-up gantries at the surface.

After 405m of excavation, the presence of scrapers, parts of the mixing bars and other wear materials in the excavated muck prompted a cutterhead inspection. With high pressure of up to 3.5 bar, the first hyperbaric intervention through an EPBM in Mexico was required.

"The interventions were the biggest challenge," said Carrillo. "The great influx of water tested the limits, because we were excavating on a decline. The interventions were costly and time-consuming."

In 2011, the machine was fast-tracked to bore a 3.9km long section of Lot 1b, a critical part of the project that needed to become operational right away to prevent chronic seasonal flooding. "The EPB proved itself while using conveyors in the sticky clays of Mexico City with very high percentages of water content, up to 400%," said González. The machine achieved rates of up to 592.5m in one month, a record among the EPBs used on the project. After completing the 3.9km bore in just 15 months, the machine was sent to Lot 5, where modifications were made for a section of mixed ground and rock.

For the 6km long Lot 5 section, the Robbins TBM was launched at the end of 2019 from the deepest civil works shaft in Mexico, at 150m, to excavate mixed face conditions and abrasive basalt rock for contractor ICA.

The machine was assembled in a 28m long chamber at the bottom of the launch shaft with the back-up gantries installed after advancing 150m. "Assembly of the EPBM required great coordination of ICA engineers, high capacity cranes for the assembly and human resources to keep to the ten-week schedule for assembly," said González.

The TEO expands wastewater capacity for Mexico City, adding 150m³/sec to the Valley of Mexico system, as well as alleviating the risk of flooding in critical areas. It will convey wastewater to the largest wastewater treatment plant in Mexico. The massive tunnel includes 24 shafts, ranging from 23m to 150m deep, plus an exit portal at the treatment plant in the Municipality of Atotonilco, in the State of Hidalgo. ■

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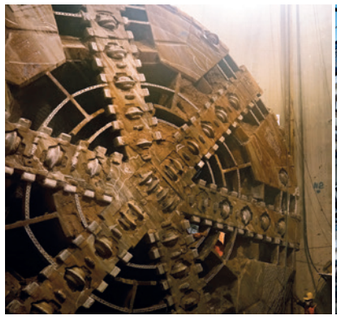
EPBM breakthrough at Lot 5; Robbins conveyors hauled muck behind the EPBMs



Buenos Aires outfall excavation nears completion

Salini Impregilo News Release

Started in 2017, excavation of a near 12km long outfall under the River Plate is nearing completion. Constructed by Salini Impregilo, the outfall is part of a megaproject by the Government of Argentina to clean up the Matanza-Riachuelo Basin in Buenos Aires.

The project will intercept wastewater from the Riachuelo treatment plant using a drop shaft made from four interconnected circular shafts to a depth of about 45m. Treated effluent will then run through a 12km x 4.3m i.d. outfall tunnel under the bed of the River Plate excavated by a 5m diameter Herrenknecht EPBM. The last 1.5km diffusion section will be fitted with 34 vertical raisers for final discharge of the effluent into the river.

Prototype riser jacking equipment, designed and built by Italian civil engineering company Palmieri, will install the risers through the geology of alluvial soils, clayey sands, and soft clay.

The project addresses contamination of the Riachuelo river basin caused by a sharp increase in the city's urban development and industrial activities such as paper mills and tanneries, that discharge process by-products into the river. It is part of a broader USD$1.2 billion plan, financed by the World Bank for sustainable development of the Matanza–Riachuelo Basin and clean up of waters that are considered among the most polluted in the world. The project is due to be fully completed in 2022. ■

Access shaft for under river outfall

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THE AMERICAS


120,000m² depot of the Quito Metro Line 1

Sustainability key for Quito Metro, Ecuador

Fernando Vara, ACCIONA Global Business Development Director SBU Tunnel & Railways

Quito Metro Line 1 can be considered one of the most sustainable and remarkable projects of South America. It demonstrates that execution of a large-scale project can go hand in hand with sustainability and respect for the environment and of the residents. The line runs under the dense capital city of Ecuador, which is a UNESCO World Heritage Site and is regulated by strict environmental and archaeological requirements.

At an overall investment of €1.6 billion, Line 1 is 22.9km long with 19.5km running through 9.4m o.d. (8.43m i.d.) single-tube double-track running tunnel and the remainder in cut-and-cover. The project includes 13 cut-and-cover underground stations, 28 pumping, ventilation, and emergency exit shafts, a warehouse and maintenance facility and installation of 45.5km of track. The line will link the south, the center, and the north of Quito in 34 minutes, transporting 400,000 people/day and creating a dynamic new transport system for the citizens. Once in operation, Quito city will reduce fuel consumption up to USD$50 million/year and achieve a reduction of 67,000 tons of CO_2 emissions.

The 19.5km bored tunnel section was excavated using three 9.4m o.d. EPBMs through various challenging formations ranging from anthropic fill, silts and clays of the Cangahua Formation, and lutites with sand, volcanic ash, and pyroclasts of the Machangara Formation. These variable ground conditions, combined with about two-thirds of the alignment being 10m under the ground water table and under water and fines pressure, required EPBM excavation. Precast concrete segments of 45 MPa strength and six segments and a key in rings of 320mm thick x 1.5m long line the drives. More than 100,000 segments, reinforced with steel rebar and 20kg/m³ of steel fibers, were produced in two casting factories located close to each portal.

In an innovative development, a fully refurbished TBM, owned by ACCIONA and used initially on the Madrid Metro in Spain, reduced the cost of TBM procurement and shortened the delivery to site schedule of one of the three machines. The refurbished Herrenknecht machine excavated 6,864m and achieved best weekly performances of more than 373m and best daily rates of 60m. The second new TBMs, supplied by Herrenknecht, surpassed these figures, excavating 80m/day and 1,489.5m in 30 days, setting a new world record for EPBMs in the 9m diameter range.

From the environmental perspective, good environmental practices for the construction works was foremost in the UNESCO World Heritage city. These included rescue of urban fauna with transplant of 107 trees, construction of three urban orchards in construction camp sites and reuse of construction materials including the use of jet grouting waste for the repaving of roads in an outer neighborhood of the capital, reuse of 72,751m³ of water and recovery of more than 2.3 million kg of recyclable waste. More than 997 tonne of wood materials were donated to the community for various activities including carpentry, guitar and furniture making, and as fuel for wood-fire ovens.

More than 5,000 daily workers were engaged on the project at the peak. With these levels of activity, safety was a priority. In 2018 and 2019, the lost time incident rate (LTIR) indicator of safety was 0.55 and 0.82 and the lost time incidents severity rate (LTISR) was 9.09 and 12.12, respectively, well below the national average. In comparison, the 2017 safety data for the Quito city region was 14.68 LTIR and 58.75 LTISR. The low index for the project was achieved by the implementation of more than 700 safety initiatives during the construction phase.

Quito Metro Line 1 is a reference project to inspire others to respect the environment, respond to traffic problems and promote the use of underground space as offering sustainable and socially responsible alternatives through their long life-cycle. There have been no claims or major commercial disputes during project execution, which emphasizes the satisfaction of the client and the advantages of the state-of-the-art project management and execution of complex infrastructure under high quality and sustainable standards. The project has been nominated for various awards including the 2019 Development Superheroes Award of the Inter-American Development Bank and has been submitted for the ITA Awards of 2020 in the category of Project of the Year of more than €500 million. ■

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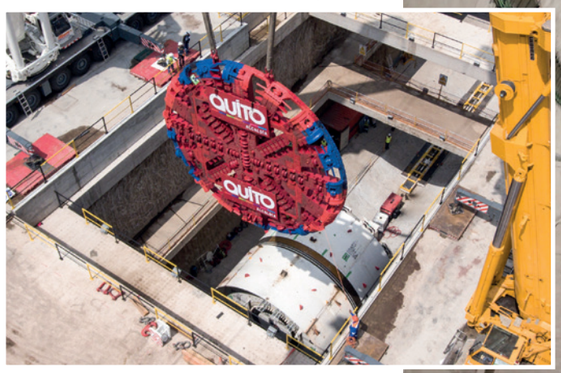
Right: Top quality single-tube, double-track metro alignment; Below: First of three EPBMs in assembly



Undersea drive for slurry TBM in China

CREG News Release

A 12.26m diameter slurry TBM is excavating a 2.9km long double-track metro tunnel under Barracuda Bay in Dalian in northeast China. The TBM, designed and supplied by China Railway Engineering Equipment Group (CREG), will excavate through highly karstic conditions under the Yellow Sea.

The tunnel, with 2.3km passing under the sea and the remainder under the landfalls, will operate 12m to 22m below the seabed and under a sea level of 9m to 14m.

The tunnel passes mainly through moderately weathered dolomitic limestone, dissolution stratum, calcareous slate and there are some moderately weathered diabase intrusive dykes in the sea area. The geology presents a complicated construction environment with high associated safety risks. The TBM includes a double-crusher system and a customized main drive capable of telescopic cutterhead movement and rotation in both directions to allow the changing of cutting tools under atmospheric pressure.

Since the start of the project, designers from the Central Design and Research Institute of CREG have carried out field investigations and designed the TBM to cope with the difficult construction

Assembly of the 12.26m cutterhead

requirements including the high probability of encountering karst voids. CREG engineer Zhang Guoliang said: "As well as the seabed, this machine needs to underpass sensitive areas including the port railway, the harbor and the wharf. The TBM is also equipped with efficient probe drilling and pre-grouting systems to improve the geological suitability and equipment reliability as necessary."

The tunnel is a main element of the Dalian Metro Line 5 project. The undersea section will link Dalian Railway Station and the Barracuda Bay South Station and will accommodate two metro rail tracks, one on each deck. The project is a public-private-partnership between the China Railway Investment Group, Dalian Metro, and Chongqing City Transportation Development & Investment Group. Dalian Metro Line 5 will provide a large capacity and high speed north-south transportation corridor to relieve surface traffic congestion and integrate both sides of the city across the bay.

The high-specification machine was developed jointly by CREG and The First Engineering Bureau CREC and was named Haihong, Hai meaning sea, and hong meaning grand. The machine passed its factory acceptance test successfully in July 2018 in the CREG manufacturing base in Dalian. Since its launch in mid January 2019, it is progressing smoothly and according to the daily advance rate of two rings/day. ■

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Early breakthrough in Nepal for Bheri Babai

TunnelTalk reporting

After an impressive drive through geological challenges in the Himalayas, breakthrough is a year ahead of schedule for the 12.2km Bheri Babai multipurpose water conveyance TBM drive in western Nepal. The 5m diameter TBM from Robbins made the breakthrough for contractor COVEC, the China Overseas Engineering Company, in April 2019.

The TBM was expected to progress 400-450m/month through the young geology of the Himalayan foothills to complete the drive in 26-30 months. The well-managed operation of the well-prepared TBM completed the drive through favourable sandstone and mudstone in 18 months. The double-shield TBM, erecting a hexagonal segmental lining, recorded up to more than 1,000m/month, working two 12hr shifts/day, seven days/week.

As the first TBM drive in Nepal, the inter-basin water transfer project attracted significant attention. The breakthrough was officiated to great celebration by Nepal Prime Minister KP Sharma Oli, and was attended by Chinese Ambassador to Nepal, Hou Yanqi, and USA Ambassador to Nepal, Randy Berry.

"Nepal is now ready to walk and work together with the international community towards the new direction of development," said Prime Minister Oli, who expressed gratitude to the Chinese contractor and a desire to use new technology for future projects.

Breakthrough of the tunnel marks completion of the first TBM drive in one of the world's least developed countries. The USD$107 million project will provide irrigation for 51,000 hectares of land and secure fresh water supplies to the western Nepal town of Nepalgunj.

The multipurpose irrigation-hydro project is one of many strategic projects in Nepal. Phase two of the project is a 48MW hydro power plant as part of the water conveyance scheme. ■

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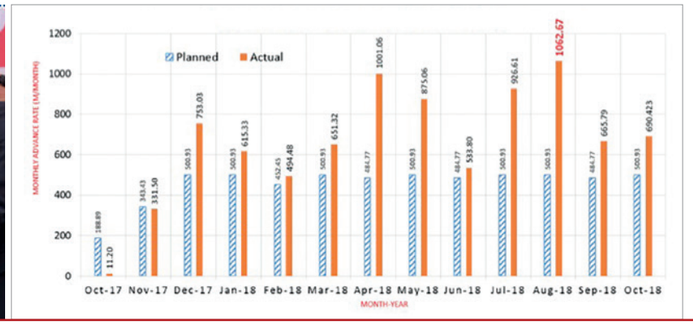
Left: Nepal Prime Minister KP Sharma Oli (centre) at the TBM breakthrough with COVEC Project Manager Tianran Hu (left) and Project Director Sanjeeb Baral for the Nepal Department of Irrigation; Right: Progress of the double-shield TBM, October 2017 - October 2018



Chinese horseshoe-shaped TBM operation

Wang Jianghong, China Tiesiju Civil Engineering (CTCE) Group and Roland Herr, *TunnelTalk*

A new horseshoe-shaped TBM, developed in China and manufactured by CREG, was used to build the 3.4km long Baicheng Tunnel through loess on the Menghua railway line. Receiving the 2018 ITA Award for the best technical innovation, the new EPBM replaced the NATM drive originally planned for the project, leading to a 10% to 15% cost saving on excavation. With about 560km of road and rail tunnels to be excavated in loess during the coming five years in China, the prospects look positive for the new TBM concept.

The Baicheng Tunnel is located in Shaanxi Province in central China, bordering the Inner Mongolian Desert and the north China loess plateau. The prevailing geology includes quaternary to sandy new loess and soft rock. The double track railway tunnel is part of a rail link between Mengxi and Huazhong, which transports coal from the north to central China. It is set to replace the previous system, which involved switching from rail to ship. The overburden of the tunnel varies from 7m to 81m. About 2.7km of the TBM drive was undertaken in rock class V and 305m in rock class VI with an additional 300m long section constructed by cut-and-cover.

The almost 11m high x 12m wide x 118m long horseshoe-shaped EPBM was developed specially for the project by the Chinese company Mengxi Huacheng Railway Co, China Tiesiju Civil Engineering Group, China Railway Engineering Equipment Group (CREG) and China Railway Design Corp. The shield mainly consists of nine smaller cutterheads with diameters of between 1.1m and 4.9m, plus two screw conveyors and two agitators in the lower part of the shield and cutting shoes primarily set up in the lateral areas of the shield. In July 2016, the EPBM was assembled and tested at the CREG factory in China before being shipped to the construction site and commencing excavation in October 2016. Breakthrough was celebrated in January 2018 and the tunnel is now operational.

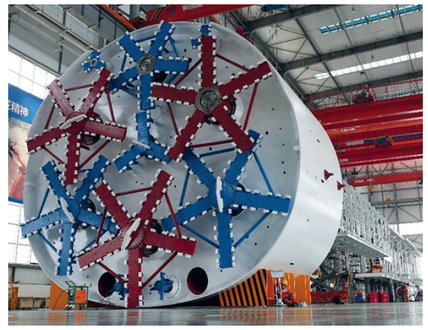
The new TBM was developed to excavate the tunnel profile more accurately than the NATM method. This resulted in significant savings of material excavated and shotcrete used to backfill excavation overbreak. Backfill of the invert to create a level rail deck was also reduced. According to the contractor, about 37% less steel, 42% less concrete and 27% fewer ground anchors were deployed and a 15% smaller area was excavated compared to the open face NATM excavation alternative. The amount of energy consumed on site was also substantially reduced.

The TBM required a launching frame at the entrance portal, which had to be adjusted for its U-profile shape. A wide concrete trough was constructed in the lower section and a steel ring set up as an abutment. The EPBM is limited to operating in soft soils or low- strength rock. At the working face, the cutter wheel concept was adapted for the special geometry of multiple smaller, partially overlapping cutterheads. Blind gaps and small corners occur where the cutterheads fail to cover the working face. The cutting shoes, mounted on the front shield, remove the ensuing material.

In the lower section of the machine there is a larger area available on account of the greater space occupied by the horseshoe shape compared to a round TBM. At the working face, the extracted spoil falls downwards and is carried away by two screw conveyors. Two agitators are set up between the screws, ensuring that the material does not accumulate. The spoil is carried to the screws, which are mounted towards the outside to avoid plug formation. The screw conveyors are driven by a common hydraulic aggregate. The earth balance is controlled by the material carried through the screws. It is essential that the screws run in synch and that the material is removed uniformly from the cutterhead area. The spoil is carried away by a continuous belt conveyor, which is covered outside the tunnel so that freezing of the soil and, in turn, blockages are avoided when extremely low temperatures are experienced.

The segments and rings of the precast segmental lining were produced to correspond with the horseshoe shape of the TBM and tunnel profile. With varying radius around the lining ring, a vacuum erector could not be used for installing the individual segments. A mechanised gripper system was therefore developed instead.

The potential of shield roll is considerably less for a horseshoe-shaped TBM than for a circular shield. To counteract roll, each individual cutterhead can rotate in either direction during the drive so that the entire TBM can be controlled more easily. The occurrence of a deflecting force that would lead to the shield rolling is practically impossible. A navigation



New horseshoe-shaped EPBM

system continuously plots the direction of the machine while controlling rolling and enabling any deviations to be identified and corrected.

Foam nozzles are installed in the shield, as for any other EPBM. These are located in the plenum bulkhead. For the horseshoe-shaped TBM, foam lubrication of the shield is particularly important as only a small overcut, or no overcut at all, is created. The danger of clogging without lubrication is also significant. The shield is always in contact with the soil and bentonite must be added, especially in areas where the overcut is limited and the cutting shoes are in operation. This lubricates the shield so it can advance easily through the soft ground. Owing to geological conditions, the TBM operated continuously in closed EPB mode with a manlock allowing access to the pressurised excavation chamber for maintenance and repairs.

Providing the geological conditions are favourable, the horseshoe-shaped TBM can save on the volume of excavated material, construction materials and construction time. ■

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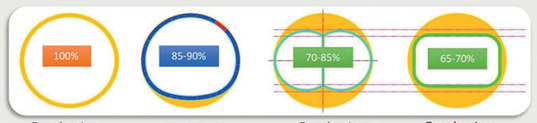
Tunnel Section Utilisation Comparison

△ = Normal
○ = Good
◎ = Very good

Items	Large-Diameter TBM	Horse-shoe Shaped TBM	Double-O-Tube (DOT) Shield TBM	Rectangular TBM
Tunnel Cross-section	Medium Utilisation Not fully used	High Utilisation Low Wasting	High Utilisation Low Wasting	High Utilisation Low Wasting
	△	○	◎	◎
Tunnel Depth (Shaft Depth)	Large	Large	Reduced	Reduced
	△	○	◎	◎
Economical Efficiency	Normal	High	Good	Very Good
	△	○	◎	◎



Segmental lining and mechanical erector; Double screw conveyors

Metro Orange Line progressed in Bangkok

Terratec News Release

A Terratec 6.39m diameter EPBM has made good progress on one of three underground civil works contracts for the first 23km-long east phase of the Bangkok Orange Line for contractor Italian-Thai Development (ITD), achieving progress rates of up to 18 rings/day.

Contract E3 totals more than 6km of TBM excavation and three underground stations, extending from Hua Mak to Khlong Ban Ma.

The TBM was designed to excavate the variable soft ground geology of the city, which ranges from soft and medium to stiff and very stiff clays, with lenses of dense sand and the potential for high pressure groundwater inflows. In addition, it will excavate through numerous diaphragm wall shafts and, potentially, concrete piles.

"We are in a very congested area of the city, tunnelling underneath a busy highway and buildings with deep foundations on both sides, so we need to carefully protect those structures," said Prakin Arunotong, Senior Vice President of ITD MRT Business Unit.

The TBM soft ground cutterhead features a spoke style and the addition of back-loading knife bits to assist break-in and break-out of the shafts. The machine is fitted with an active bentonite face support injection system and a double gated screw to ensure face stability and mitigate settlement during excavation in areas of flowing sands and high groundwater pressure.

Terratec 6.39m diameter EPBM

EPBM ready for launch

The machine will install a precast concrete segmental lining consisting of five 1.2m wide universal style segments plus key, with an internal diameter of 5.7m.

The Bangkok Metro Orange Line will eventually total 35.4km with 26.2km aligned underground and 23 underground stations. Another 9km and seven stations are on elevated structures. The Orange Line will provide a vital transportation link from Bangkok city centre to districts in the east, reducing traffic congestion and paving the way for improved accessibility, economic growth and new residential and commercial opportunities along the alignment.

Terratec has now delivered seven TBMs to underground works projects in Thailand in the last three years, representing every type of machine currently being operated in the country. ■

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Tight curve drive breakthrough in Bangkok

Terratec News Release

The first of two EPBMs on the complex Chidlom cable tunnel project in Bangkok celebrated a successful breakthrough. The 3.2m diameter Terratec machine completed a challenging portion of the project that included a tight 35m radius curved drive for contractor Italian-Thai Development (ITD).

Running from the Central Embassy mega mall southwards to Lumphini Park, the project, for the Metropolitan Electricity Authority, is located in one of the most exclusive and built up areas of downtown Bangkok (Fig 1). To remain within public road easements and negotiate building foundations and the deep piles of the Sukhumvit Skytrain, the tunnel drive alignments require several tight radius curves to bring them into the Chidlom electrical terminal station. To achieve this, the EPBMs have been designed with an X-type articulation system.

"We have worked closely with Terratec on several projects in the past and have had a close collaboration with the company from the tender stage of this project," explained Project Manager Supak Khunviriya for ITD.

The soft ground TBM cutterheads feature an open spoke design with the addition of knife bits to assist break-in and break-out of the concrete shaft eyes. Universal tapered precast concrete segments are typically installed as the machines progress, with shorter steel segment sets utilised during the course of the sharp radius curves. The geology along the project is typical for Bangkok, generally comprising stiff to very stiff clay, with lenses of sand and a groundwater head of about 2 bar.

Fig 1. Tight curve TBM drives follow public road easements; Short steel segment rings follow the TBMs through the sharp radius curves

"We started out straight into the 35m radius curve with the first machine, going under a busy five-lane road and around the corner of a department store at the intersection with Phloen Chit Road," explained Khunviriya. "This is an old building, so the foundation piles extend down to about 20m. The tunnel is at exactly the same level, so we had to be very careful not to cause any settlement. We also had to negotiate the Skytrain foundations on the other side, giving us a window with about 1m either side of the machine through the intersection."

An array of monitoring equipment recorded zero movement during the curved drive. ITD credits much of this success to the skill of the Terratec field service team, whose experienced TBM operators steered the TBM throughout the curve and which is assisting TBM operations and maintenance throughout the project.

Designed to accommodate a new high-voltage cable system, the Chidlom cable tunnel project is one of a series being built to answer increased power demands in the Thai capital by the Bangkok Metropolitan Electricity Authority. The projects will improve the reliability of the power transmission system. ■

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Kolkata TBM failure causes extensive damage

TunnelTalk reporting

Tailseal failure on the EPBM operating on a running tunnel drive for the Kolkata Metro caused an uncontrollable inrush of water and material that led to major damage and collapse of buildings. The inrush took a day to control, with residents evacuated from damaged and collapsing homes and businesses in the central Bowbazar area.

The September incident occurred 1.6km into the lead heading of the 2.45km running tunnel drives for the new East-West Metro line from Esplanade to Sealdah Stations. Senior executives of the Kolkata Metro Rail Corporation (KMRC) said the machine had just taken a tight radius turn into an alignment under Ganguly Street, placing severe pressure on the three-row wire brush tailseal. The turn occurred as the machine entered an unexpected geological deposit of highly water-charged sand. The inrush of water and sand through the damaged tailseal quickly became uncontrollable, flooding the tunnel and the TBM, and causing collapse damage on the surface.

The Esplanade to Sealdah drives are part of the eastern 4.5km section of the new metro line that runs between Esplanade to the transition ramp of an elevated guideway to Salt Lake Sector V and are being advanced by the ITD/ITD Cementation Ltd JV. The JV is using two refurbished EPBMs that ITD procured from Herrenknecht 10 years ago for work on the Delhi Metro. The lead machine launched from the Esplanade Station box in February 2019. The twin machine launched about a month later.

Both TBMs are at an indefinite standstill awaiting work to stabilise the collapsed area, assess the condition of damaged buildings, and secure the tunnel drive. More than 450m^3 of concrete was injected from the surface and from within the tunnel to stop the inflow of sand and water and continued for the following days to fill the ground-loss void.

A senior management spokesman for KMRC told *TunnelTalk* that in addition to the volume of concrete pumped into the collapsed area, "a bulkhead of poly-fibre reinforced shotcrete was installed at the end of the 75m TBM to prevent water flowing back into the working shaft. Another bulkhead of cast concrete was installed about 5m behind the first." He confirmed that, "the 6.35m diameter TBM is completely flooded" and that "it is not known the state of the 5.8m i.d. segmental lining ahead of the shotcrete bulkhead."

Managing Director of KMRC, Manas Sarkar, explained that, "in normal situations [when encountering poor ground conditions] we inject a mixture of concrete and certain chemicals to plug the holes. But this time, no matter how much we pushed the mixture in, it was getting washed out. After we failed to bring the situation under control, we began evacuating the homes." Officials told local media reporters that the aquifer of sand and water could not be identified during pre-excavation ground surveys beneath the streets of one of the oldest and most dense urban areas of the city.

Industry Feedback

From: Siba Prasad Sen, Independent Consultant, India

With regards to the reported Kolkata Metro drive collapse, I believe this took place as the TBM entered a buried tidal channel. Kolkata is built over the delta of the Ganga-Brahmaputra confluence on sand and silt. As a result, there are many such buried tidal creeks below the city. It is hard to accept the statement that geological investigation during planning did not indicate the presence of any water body. For such cities, geological studies are always insufficient and should be supplemented by geo-anthropological study. ■

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Vishnugad Pipalkoti TBM finally set to start

Patrick Reynolds for *TunnelTalk*

A TBM set to excavate the majority of the 13.4km long headrace tunnel for the Vishnugad Pipalkoti hydro project in the Indian Himalayas was prepared for launch after years of delays.

The plan was to launch the new 9.86m diameter double shield three years ago after main contractor Hindustan Construction Co (HCC) awarded the TBM tunnelling subcontract to Seli Overseas. While manufacturer Terratec had the TBM ready to despatch in 2016, the project developer, Tehri Hydro Development Corporation India (THDC), reported slow progress by HCC on much of the early tunnelling works, including preparing the TBM launch area. Shipment of the TBM was therefore delayed.

HCC was awarded the engineering, procurement and construction (EPC) contract to build the 444MW Vishnugad Pipalkoti project five years ago. Early underground works by HCC have included drill+blast excavations for access adits, the diversion tunnel and the powerhouse complex.

The major tunnelling task yet to start is the majority of the 13.4km long headrace tunnel which will convey water to the power plant on the Alaknanda River in Uttarakhand Province. To date, the balance of work on the headrace has been excavated by drill+blast.

Gianluca Ciocca, India Projects Director for Seli Overseas, said that the TBM should be launched in November 2019 to start boring the main reach of the headrace tunnel. The machine specification was developed by Terratec with Seli Overseas, which will supply the operating crew. The machine will be able to switch quickly from double to single shield EPB mode.

Ciocca said the 12.3km long TBM bore is expected to take 36 months. "The geology for the first 200m of the drive is quite critical," he said, "consisting of mainly sandy silt layers. For this stage, we will use face consolidation, chemical grouting and hand mining to open a top heading."

Beyond the initial section, competent rock is anticipated, consisting of low grade quartzitic sandstone, dolomitic limestone, and slates with metabasic sills and dykes.

Seli Overseas and HCC previously experienced success in the complex geology of the Himalayas at the Kishanganga hydro project in Kashmir with a 6.18m diameter double shield. In the past, TBMs have suffered from problems when excavating hydro tunnels in the Himalayas resulting in most tunnelling projects using the slower drill+blast method. ■

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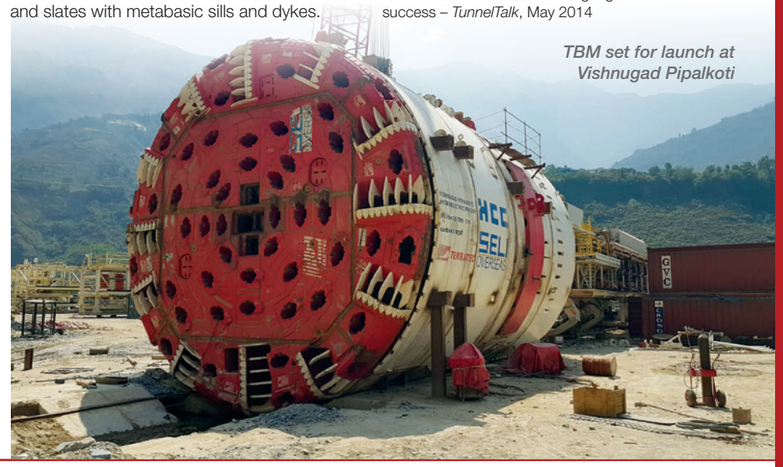

TBM set for launch at Vishnugad Pipalkoti

TBMs delivered for Pune Metro in India

Terratec News Release

Following successful factory acceptance tests, the first two of three Terratec 6.6m EPBMs were delivered to the Gulermak-Tata Projects JV for its underground works contracts on Line 1 of the Pune Metro project, in Maharashtra State, India. This follows a major funding milestone for the project signed off by the European Investment Bank. The two other TBMs for the project were being manufactured at the Terratec assembly plant in Nansha district, Guangzhou, in Guangdong province, China

Early in 2019, Maharashtra Metro Rail Corporation (MahaMetro) announced that the joint venture had won both packages of the twin-tube underground alignment of the new 16.6km north-south metro corridor. The 5km underground section with five underground stations that runs from the College of Agriculture in Shivajinagar to Swargate, is considered the most challenging portion of the line, as it passes under the densely populated areas of Kasba Peth, Budhwar Peth and Mandai market.

Along with the twin-tube EPBM drives, the Gulermak-Tata Projects JV includes design and construction of the Shivajinagar and Civil Court underground stations on contract UGC-01 and the Budhwar Peth, Mandai and Swargate underground stations on UGC-02 (Fig 1). Contract award value of UGC-01 is a combination of USD$124.2 million in Indian Rupees plus USD$37.6 million, and for UGC-02 is USD$119 million in Indian Rupees plus USD$40.57 million.

"We are ready to launch the first two Terratec TBMs," said Ashish Dwivedi, Geotechnical Manager for the Gulermak-Tata Projects JV. "Terratec TBMs have a successful track record in India with seven currently working on the Mumbai Metro. We expect to complete our 5km Pune Metro Line 1 twin tube excavation within the project schedule." Major challenges on the project will include passing beneath century-old surface structures, crossing under the River Mutha and launching and retrieving TBMs with limited access in the built up areas near Budhwarpeth and Mandai Stations.

Terratec EPBMs have robust mixed-face dome-style cutterheads designed to work effectively in the compact basalt expected on the alignment of the two contracts.

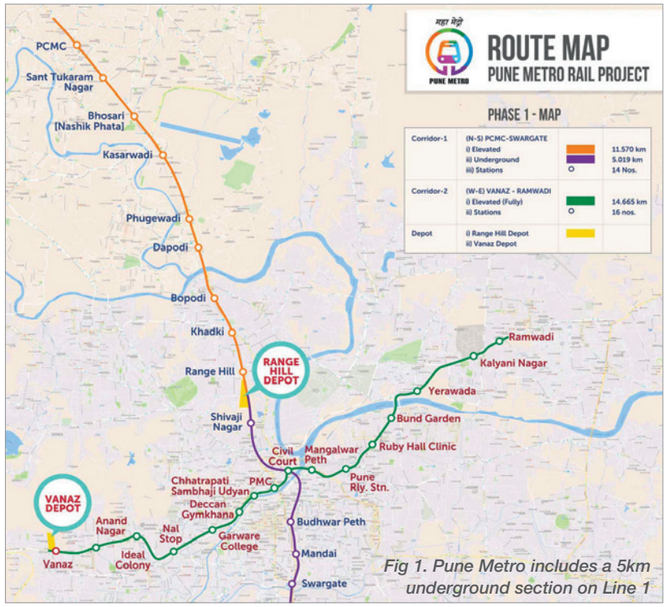

Fig 1. Pune Metro includes a 5km underground section on Line 1

"Gulermak-Tata has again put its confidence in our machines," said Gulshan Gill, Managing Director of Terratec India. "In recent years, Terratec has emerged as the leading TBM supplier in the Indian market, with continuing success on underground sections of Phase III of the Delhi Metro, the Lucknow Metro, the Ahmadabad Metro and the Mumbai Metro. The success is due to purpose designed TBMs, prompt onsite assistance, readily available stock of spare parts, and skilled specialised support," added Gill.

As the TBMs progress, they will operate at pressures of up to 4 bar and will install 1.4m wide x 275mm thick rings of precast concrete lining, consisting of five segments plus a key in each ring.

Local contractor Kumar Infraprojects was awarded a works package in mid-2018 to perform shaft access works at Agricultural College and Swargate, where it will also construct the multimodal transportation hub on top of the underground station built by the Gulermak-Tata JV. Consultancy services to the client for Line 1 are provided by Systra, AECOM, EGIS and RITES.

Pune is an industrial city that has witnessed much growth in the areas of corporate and industrial infrastructure over the last decade. Existing roads in the city currently carry an average of 8,000 commuters an hour in each direction and the city experiences hours of traffic jams during peak hours that leads to increased pollution.

The Pune Metro aims to provide a solution to the issues by offering a safe and eco-friendly journey with a 50% reduction in travel time.

With two lines in development, the project is constructing a total 31.3km network with 30 stations. The budget for the complete project is almost €1.8 billion (USD$1.9 billion). A major development for the project is agreement by the European Investment Bank of a loan of €600 million (USD$657 million). Additional funding of €245 million (USD$268 million) is being supplied by the French Development Agency.

When complete, in 2022, the Pune Metro network will comprise three rail corridors with a total length of 54.5km. ■

References

- Twin Crossover TBMs prepare for Mumbai Metro drives – *TunnelTalk*, July 2018
- Double TBM breakthrough in Lucknow – *TunnelTalk*, October 2017
- Progress and plans for city metro systems in India – *TunnelTalk*, November 2016

From left: Terratec TBMs successfully factory tested; Design of Swargate multimodal station hub

Hard rock TBM for Mumbai water transfer

Terratec News Release

A hard rock open gripper TBM of 3.2m diameter ordered from Terratec by Patel Engineering is completing two drives for a 5.5km long Amar Mahal II water transfer tunnel contract for the Municipal Corporation of Greater Mumbai in Maharashtra.

To work effectively in the mixed basalt conditions expected along the alignment, at an average depth of 80 to 90m below the surface, the Terratec open gripper TBM is equipped with 22 x 15in back-loading disc cutters and fitted with anti-wear plates and lubrication systems to assist with wear prevention and dust suppression. In addition, the machine will be fitted with drilling systems for probing and pre-excavation grouting and for installing rockbolts. It will have a steel arch erector and shotcrete pumps to assist in ground support activities.

"This will be the 25th Terratec machine delivered to India in the last six years," said Bruce Matheson, Terratec Sales and Marketing Director. "It continues Terratec successes on projects including Phase III of the Delhi Metro and on the Lucknow, Ahmadabad, Mumbai and Pune Metros where prompt onsite assistance, a readily available stock of TBM spares and specialised support is offered throughout the tunnelling operation." ■

References

- First TBMs delivered for Pune Metro in India – *TunnelTalk*, November 2019
- TBM drives under old town Mumbai – *TunnelTalk*, August 2019
- Double breakthrough after challenging drive in Lucknow – *TunnelTalk*, June 2018
- Delhi Heritage Line moves closer to completion – *TunnelTalk*, February 2016

Terratec gripper TBM for Mumbai water transfer

Breakthrough celebrations in Mumbai

Terratec News Release

Excavation of the 3.8km southbound link between Chhatrapati Shivaji terminal and Mumbai central station on Mumbai Metro Line 3 has been completed on a route that required the TBM to advance delicately under some of the oldest buildings in Mumbai. Following breakthrough of the 6.7m diameter TBM, the section UCG-02 became the first of seven contract packages to be completed. Contract UCG-02 was awarded to the Hindustan Construction Company-Moscow Metrostroy Joint Venture in July 2016. It is using one of seven Terratec TBMs being used on Line 3.

When finished, the 33.5km long Line 3 will be the first underground metro in the city and will connect Cuffe Parade business district in the south to the Santacruz Electronics Export Processing Zone in the north, with 26 underground and one at-grade stations.

With production rates of up to 24m/day, the production record for the project, the machine was driven via NATM-excavated station boxes at Kalbadevi, Girgaon and Grant Road, at an average depth of 20m, through basalt, breccia, and tuff, as well as reclaimed sand with negligible settlement. Excavation was completed on schedule, despite challenges that included proximity to the ocean, boring through reclaimed land, and congested working areas, as well as mining beneath some of the oldest parts of the city.

"Most of the tunnel alignment is under the oldest and most densely populated area of south Mumbai with many dilapidated residential buildings," said Ravi Ranjan Kumar, Chief Project Manager for Mumbai Metro. "The performance of the dual-mode TBM in this geology was lhighly satisfactory."

The first of the TBMs to break through on Line 3 was on the first 690m section of the UGC-06 contract from the CSIA International Airport Station to Sahar Road Station. It is one of three Terratec dual mode hard rock TBMs working for the J Kumar/China Railway No 3 Engineering Group (CRTG) JV on the 4.45km-long twin-tube UGC-06 package and on the 4.94km long twin tube UGC-05 contract. "The Terratec dual-mode TBM worked successfully through mixed geology and considerable water ingress," said Haluk Emre, Package 6 Project Manager for the JV.

The Terratec single shield TBMs are equipped to operate in either open or closed mode. The hard rock cutterheads are equipped with heavy-duty 17in cutters, which are interchangeable with ripper tools, and feature large bucket openings to provide a 10% opening ratio. The 2,000kW electric variable frequency drives provide a maximum cutterhead rotation of 7 rev/min and a torque of up to 8,500kNm to excavate efficiently in harder rock zones and cope with more fractured zones. The machines have active shield articulation and a two component annular backfill grout system.

Construction of the line is divided into seven tunnel and station packages that were awarded to five contracting joint ventures in 2016. These five contractors will deploy a total of 17 TBMs with Terratec being the lead TBM supplier of seven machines on the project, equal to a 41% market share. Terratec field service support experts are on call to assist TBM operations with close monitoring throughout. ■

Contract packages on the 33.5km Mumbai Metro Line 3

References

- Progress on Mumbai Metro Line 3 – *TunnelTalk*, September 2018
- First deliveries to Mumbai with more to follow – *TunnelTalk*, August 2017

UCG-02 is the first section to be completed

Talbingo power station and the reservoir that is to become the lower basin of the Snowy 2.0 scheme

Snowy Mountains adds long-planned element

Shani Wallis, *TunnelTalk*

Construction of another element of the Snowy Mountains water management and hydro scheme on the borders of New South Wales and Victoria in southeastern Australia will begin following confirmed award of the civil and mechanical installation contract to the Future Generation group led by Salini Impregilo of Italy. The economics of construction versus the value of power to be generated, together with the green energy objectives in Australia, now supports the feasibility of the Snowy 2.0 project. Designed as a pumped storage installation, the scheme will link the existing upper Tantangara Reservoir and the lower Talbingo Reservoir to increase the hydro capacity of the overall Snowy Mountains installation from 4GW to 6GW (Fig 1).

In February 2019, the Future Generation JV was selected as the preferred bidder for Snowy 2.0 which includes excavation of up to 27km of headrace and tailrace tunnelling and powerhouse caverns located at up to 800m below the surface.

Salini Impregilo signed the AUD$5.1 billion (€3.228 billion) contract for the civil works and electromechanical component of the project in its capacity as the combined 65% leader of the JV with its USA subsidiary Lane Construction and with JV Australian partner Clough with a 35% stake. The contract was signed in early April 2019 with Snowy Hydro which has the Australian Federal Government as its sole shareholder. The six-year contract includes the civil works and installation of the power generation and pumping components to be supplied under a procurement contract with Voith Hydro. The underground powerhouse will contain

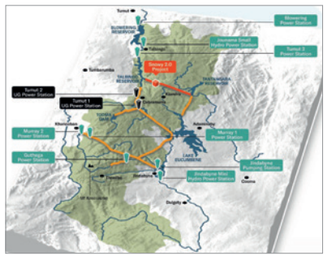

Fig 1. The Snowy Mountains Scheme

six reversible Francis-type pump turbines, three of variable speed and each with a rated output of 333MW. Voith will also supply the six motor generators and power plant automation systems.

Leed Engineering of Adelaide will perform exploratory and pre-construction works. These include a 3km long exploratory tunnel to the top of the cavern complex to confirm the best location and orientation of the powerhouse. The exploratory tunnel is to be excavated using drill+blast and TBM methods and will become the main construction and permanent access to the underground power station.

Proposals to progress with the Snowy 2.0 project came in March 2017 as part of efforts by the Federal Government towards increasing Australia's renewable energy sources. This resulted in commissioning of the $29 million feasibility study by SMEC for Snowy Hydro.

In March 2018 the Federal Government of Australia became the 100% shareholder of Snowy Hydro by buying out the 58% share held by the State Government of New South Wales and the 29% share held by Victoria State for a total cost of more than $6 billion.

Snowy Hydro Chief Executive Paul Broad said it was negotiation in November 2018 of favourable long term supply agreements with solar and wind generators for supply of off-peak energy to pump water back to the upper reservoir and provide an estimated 175 hours for peak demand storage that contributed to the favourable economics of advancing Snowy 2.0, improving anticipated returns of the project to about 9%.

Approval to progress with construction in February 2019 committed a Federal Government equity investment of up to $1.38 billion over a six-year period. The balance is to be financed through financial agreements secured by Snowy Hydro. With approval of the environmental impact statement, main contract works started in 2020. First power from the project is expected to be online by 2024.

Snowy 2.0 will be the largest hydro power station in Australia and will triple the pumping capabilities of the overall scheme. Snowy Hydro produces some 33.9% of the nation's current renewable energy power.

The existing Snowy Mountains Scheme, constructed between 1949 and 1974, is the largest public works engineering scheme ever undertaken in Australia and comprises sixteen major dams, nine power stations, a pumping station, up to 145km of tunnels and 80km of pipelines and aqueducts. The scheme is Australia's largest producer of renewable energy, and manages irrigation water flows via the western Murray and Murrumbidgee Rivers to a vast agricultural area of the nation. ■

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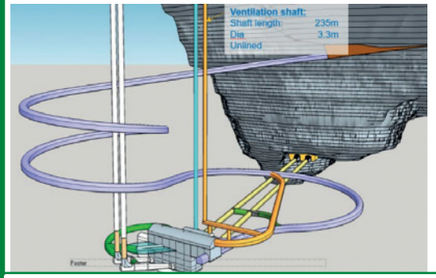
- Programme challenges at Bogong hydro project - *TunnelTalk*, March 2009

Kidston hydro set for construction

Patrick Reynolds for *TunnelTalk*

The Genex Power Kidston pumped storage project in Queensland secured key debt funding that will enable work to start on the complex underground infrastructure. Genex itself is investing AUD$25 million (USD$17 million) equity into the project, as a 50:50 co-owner with Energy Australia. The Northern Australia Infrastructure Facility (NAIF) is providing funding of up to $610 million (USD$410 million) and finding is also received from the Australian Renewable Energy Agency.

Fig 1. Major works at Kidston project;



The Owner's Engineer on the 250MW scheme is Entura, and the EPC contractor is a JV of McConnell Dowell/John Holland, with hydro machinery supplied by Andritz.

The contractor was appointed in late 2017 under an early contractor involvement (ECI) procurement process. Following financial close and the notice to proceed, the EPC contractor will begin detailed design and start main construction activities.

The underground infrastructure, based in an old gold mine, has a headrace drop shaft from the upper reservoir to the power cavern complex (Fig 1). Other excavations will include an access tunnel and cable and ventilation shafts. The main powerhouse is 82.2m long x 17.5m wide x 44m high and the transformer cavern is 31.8m long x 10m wide x 10m high. The intake shaft is 240m deep x 4.8m diameter. The two tailrace tunnels are each 160m long x 6m wide x 6m high. Most excavation will be by drill+blast, with raise boring for the shafts.

All hydraulic tunnels will be lined with steel closest to the caverns, where water pressures will be highest, and with concrete for other waterway tunnels.

The project is designed to provide about eight hours of generation at constant 250MW output, and take eight hours to pump water to the upper reservoir. The project is expected to come online in 2022. ■

References

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Sydney opens new underground highways

Jonathan Rowland, *TunnelTalk*

The M4 element of the WestConnex underground highway in Sydney opened to traffic, while work on the M5-M4 link and the Rozelle interchange continues. The 5.5km M4 route features twin tunnels with a three-lane highway in each direction and was finished on time and within its budget of AUD$3.5 billion. Running through the west of Sydney, excavation of the M4 section was completed by the CPB/Samsung/John Holland JV using 21 roadheaders and 11 Robodrill bolting rigs working across four sites. It includes 50 cross passages for a total underground excavation of about 14km.

Excavation work on the $4.3 billion WestConnex M5 contract by the CPB/Dragados/Samsung JV was completed in December 2018 and also opened to traffic in early 2020. The 9km long twin three-lane tunnels, with 75 cross passages, link Kingsgrove to a new St Peters Interchange to the southwest of Sydney. Excavation was a roadheader operation with 20 roadheaders and 11 Robodrill bolters working from four construction sites.

The Lendlease/Samsung/Bouygues JV began excavation on the third element of the underground network, the M4-M5 link, in March 2019. The 7.5km twin four-lane route connects the M4 at Haberfield with the M5 at St Peters (Fig 1).

Stub tunnels to connect the underground road network to the Rozelle Interchange and to future extensions for the Western Harbour Tunnel and Beaches Link are also part of the contract.

The final contract is the Rozelle interchange, a $3.9 billion underground junction that will be one of the largest in the world. The JCL John Holland/CPB Contractors JV was selected as the design-build contractor.

Fig 1. Full scope of the WestConnex project
Inset: The new Concord Interchange and entrance to the M4 underground highway

References

- WestConnex final link awarded – *TunnelTalk*, December 2018
- Precision roadheader and rockbolting on WestConnex – *TunnelTalk*, December 2018

Jonathan Rowland, *TunnelTalk*

Sydney Metro expansions

As work continues on the 15.5km City and Southwest extension to the Sydney Metro, planning progresses on a set of underground infrastructure that will almost double the length of the network (Fig 1). Corridors for the rapid build-out of the system are being future-proofed and early investigations have started of a Metro Greater West expansion to service western suburbs and the new Western Sydney International Airport. The objective by the Australian and New South Wales Governments is to have Metro Greater West operational in 2026, when the Western Sydney Airport is scheduled to open.

The first of the western extensions is the 24km long, Sydney Metro West underground line that will run between the two commercial districts of Paramatta and Sydney. Metro West is the third element of metro development for the state capital city of New South Wales and follows the successful opening in 2019 of the first 15km Metro Northwest line and the 15.5km City and Southwest route, which is under construction (Table 1 and Figs 2 and 3).

Planning for the twin-tube Metro West extension is underway, with the project receiving AUD$3 billion in development funding in June 2019. Funding for the project is following the same procedure used for both the Metro Northwest and Metro City and Southwest projects.

When complete, travel time between Paramatta and the city centre will be about 20 minutes. "This will transform how people move around Greater Sydney," said Jon Lamonte, Sydney Metro Chief Executive.

Under current design specifications, at least four TBMs are expected to excavate the Metro West route with roadheaders excavating the station caverns, stub tunnels, and connectors from the mainline tunnels to the above-ground Clyde stabling and maintenance facility.

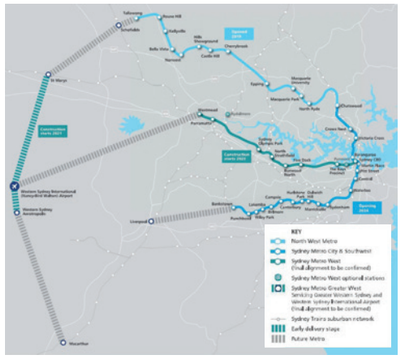
"The tunnelling packages are expected to cover about 20km of twin drives from Bays Precinct to Westmead," explained Lamonte.

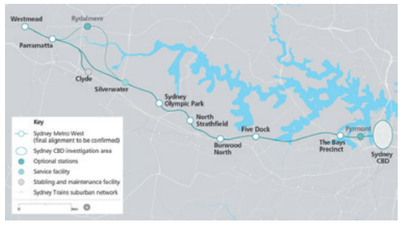
According to geological mapping, the Metro West route will run through a mixed geology of Ashfield Shale, Hawkesbury Sandstone, and quaternary deposits, such as silty-to-peaty quartz, sand, silt and clay. These ground conditions make it likely that double shield TBMs will be selected, according to Lamonte, although final machine selection will be made by the contractors.

In addition to the tunnels, there will be eight new underground stations. Of these, six are likely to be cut-and-cover at Westmead, Paramatta, Sydney Olympic Park, North Strathfield, Burwood North and Bays Precinct. Five Dock Station is expected to be a cavern design, constructed by roadheader. Designs for the central Sydney and Paramatta Stations are the subject of ongoing assessment, including community and stakeholder engagement. Additional stations may also be added at Rydalmere and Pymont.

Initial construction work on the line is expected to begin in 2020 at Bays Precinct to prepare the site for the start of tunnelling work, including site surveys, investigations, and early works such as road relocation.

Formal expressions of interest from contractors and supplies for the new lines are expected to be invited during mid-2020.





From top: Fig 1. Sydney Metro set for major expansion; Fig 2. Metro West will almost double the length of the Sydney Metro; Fig 3. 15.5km City and Southwest route to open in 2024

City and Southwest progress

Meanwhile, five TBMs, supplied by Herrenknecht, have completed the 15.5km twin tube underground route for the City and Southwest line that includes a link under Sydney Harbour (Fig 3). Four double-shield hard rock TBMs and a Mixshield for twin drives of 885m each under Sydney Harbour, were procured by the John Holland-CPB-Ghella JV when it secured the AUD$2.8 billion contract in June 2017. Bechtel is Delivery Management Partner for the client, Sydney Metro.

In addition to the twin running tunnels, the new Metro line includes six new underground stations at Crows Nest, Victoria Cross, Barangaroo, Martin Place, Pitt Street, and Waterloo plus a launch portal at Marrickville and a temporary TBM retrieval shaft at Blues Point. Under a separate contract, Sydney Central Station will be extended underground in a AUD$955 million works package awarded to Laing O'Rourke in March 2018. The AUD$1.3 billion M&E contract for the entire line was awarded to the Systems Connect JV of CPB and UGL.

Table 1. Current and planned development of Sydney Metro

Stage	Length	Status
Northwest	15km	Opened in 2019
City and Southwest	15.5km	Under construction for expected opening in 2024
West	24km	In planning. Invitation for formal expressions of interested in tunnelling elements expected in early 2020.
Greater West	TBC	In planning.

From left: Mixshield barged and transported back to the Barangaroo shaft for its second under-harbour drive; Martin Place Station cavern construction

The first TBMs for the running tunnels launched in late 2018 to excavate the 8.1km section between Marrickville and Barangaroo on a route that took them under the city's central business district to break through at Pitt Street Station, a distance of about 6km. After launch in October and November 2018 the TBMs achieved advance rates of 128m/week and 136m/week respectively.

To the north of the Harbour, the second two TBMs excavated the 6.2km alignment between Chatswood and the reception shaft at Blues Point. The first of these machines launched in January 2019, breaking through at the site of the new Victoria Cross Station in late August. After relaunch in November 2019, it bored the final 1.7km section of the alignment to the edge of Sydney Harbour at Blues Point. The second TBM was launched in mid-February 2019 and broke through at Blues Point in December 2019.

Excavation rates of up to 157m/week have been achieved by the TBMs through the competent sandstone.

The slurry Mixshield machine was the last to begin work, departing from its Barangaroo launch site on the south side of the Harbour in early August 2019. Under the Harbour, the Hawkesbury Sandstone drops below the alignment, leaving the twin tubes to pass through a reach of soft sedimentary deposits. Originally a multi-mode machine was considered for the drive, but after extensive additional geotechnical investigation by the contractor, a Mixshield was procured. This additional ground investigation also eliminated the anticipated need for additional ground treatment of the transition zones between the sandstone and sediment deposits from barges anchored in the harbour.

The Mixshield was launched from the working site in Barangaroo in June 2019. During advance under the harbour, the machine encountered more clay than expected, reducing advance rates to about 29m/week. At the end of the first 885m long drive in October 2019, the TBM was retrieved from the Blues Point site and returned on a barge across the harbour to Barangaroo to start the second under-harbour drive in early 2020.

Ahead of relaunch, some adjustments were made to improve productivity, including increasing the size of the cutterhead openings to enable the machine to excavate more efficiently through clay. Some of the soft-ground tools were also changed to improve the rate of excavation through the softer harbour sediment.

The machine took two months to excavate the second tunnel, a month faster than the first, and in March 2020 it broke through at Blues Point to end TBM excavation for the project. Five TBMs had delivered 31km of segmentally lined tunnels in 17 months.

For underground station works, the stations at Crows Nest, Waterloo and Barangaroo are cut-and-cover constructions.

At Victoria Cross, Martin Place and Pitt Street, the stations are mined caverns. The cavern at Victoria Cross is 40% larger than any other station on the Sydney Metro. At 270m long x 25m wide x 20m high, it has been excavated by three roadheaders. The Pitt Street Station comprises two 247m long x 14m wide caverns set 84m apart. A concrete pile retaining structure was built before start of excavation to support the ground during excavation. Drill+blast and roadheaders were used for station excavations.

In addition to the new Sydney Metro platforms, construction works at Central Station include an 19m wide underground passenger concourse. Excavation of the underground metro platforms began in 2018 and is expected to be complete in late 2022.

The City and Southwest line and its stations are due to open and start service in 2024. ■

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- Sydney Metro awards mega extension project – *TunnelTalk*, January 2017
- TBM record for Sydney rail mega-project – *TunnelTalk*, February 2016

Karen Martin, *TunnelTalk*

Melbourne Metro breaks ground

Tunnelling started on the PPP project of the Melbourne Metro in Victoria in 2019. The Cross Yarra Partnership of Lendlease Engineering/John Holland/Buoygues Construction and Capella Capital will deliver a 9km twin-tube link from Kensington to South Yarra as part of a new end-to-end rail line from Sunbury in the west to Cranbourne/Pakenham in the south east with new underground stations at North Melbourne, Parkville, State Library, Town Hall and Anzac.

Two 7.2m diameter Herrenknecht Mixshields were assembled at the North Melbourne Station site and were launched separately in October and November 2019. Upon reaching the western tunnel portal at Kensington, they will relaunch from North Melbourne towards Parkville and the city center (Fig 1).

A further two TBMs will launch in 2020 from the future Anzac Station in the Domain Precinct and advance towards South Yarra. They will be transported back to Domain to be reassembled and launched towards the central business district and under the Yarra River.

The AUD$6 billion project will free up space in the City Loop subway and rail system by taking three of the busiest train lines out of the loop and running them through the new underground route, allowing for more trains more often across the network.

The new metro line will be up to 40m deep (Fig 1), with the deepest point under the existing City Loop tunnels. From the station under Swanston Street at Flinders Street, the underground alignment runs below the Yarra River before passing under the CityLink highway on its way to the new Anzac Station.

To keep Swanston Street open during construction, working access shafts are being excavated adjacent to future station entrances. These working shafts will transport machinery, equipment and workers to excavate the station caverns, greatly reducing disruption on the surface. Trams will continue to travel along Swanston Street during construction.

The State Library and Town Hall stations will be built as trinocular caverns. Roadheaders will excavate three overlapping tunnels to create a wide open space with the concourse and platforms integrated on a single level, rather than two tunnels separated by cross passages. The new North Melbourne, Parkville and Anzac Stations and entrances will be built by cut-and-cover.

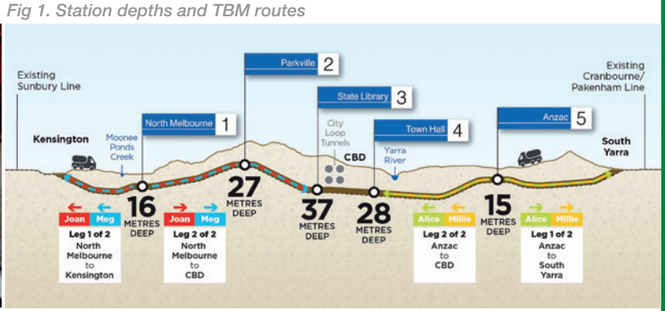
The geology of the area is variable and includes soft soils, including Coode Island Silt, with hard basalt under the Yarra River and in some sections of the western alignment. Many sections of the tunnel alignment feature a mixed-face geology. ■

References

- Melbourne awards its PPP metro contract – *TunnelTalk*, July 2017

First Mixshield assembled and ready to advance

Fig 1. Station depths and TBM routes



Shortlist for Melbourne underground highway

TunnelTalk reporting

Three consortia are shortlisted to build the 6km twin tunnels that will form part of the 28km North East Link highway in Melbourne (Fig 1). It is the largest infrastructure project in the State of Victoria and the longest road tunnel in the State.

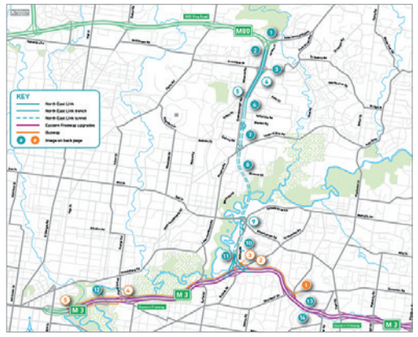


Fig 1. Proposed route of new highway

The consortia competing for the AUD$7-9 billion contract are:

OneLink, comprising CPB Contractors, Samsung C&T Corporation, Egis Road Operations, UGL Engineering, Pacific Partnership, and DIF Management Australia

Spark, comprising Salini Impregilo, GS Engineering and Construction, China Construction Oceania, Broadspectrum Australia, Capella Capital, and John Laing Investments, with advisors, Lendlease Engineering

ViaNova, comprising John Holland Group, Acciona Construction, Lendlease Services, Plenary Group, and Acciona Concesiones

The selected contractor will design the entire project, including the new interchanges, freeway upgrades, and paths for pedestrians and cyclists. Construction is expected to start in late 2021, with preparatory works starting in early 2020 following planning approvals.

Excavated by TBM, the underground section will run 40m below ground at the deepest point, 20m under the Yarra River, and at least 15m below residential properties. It is expected to open to traffic in 2027. ■

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TBM order for Auckland interceptor

Karen Martin, *TunnelTalk*

A 5.45m diameter EPBM supplied by Herrenknecht will excavate the 14.7km long x 4.5m diameter central interceptor project in Auckland. Herrenknecht was selected following a detailed multi-criteria evaluation. “A key factor in the selection was the previous experience Herrenknecht has had on tunnelling projects in Auckland, coupled with its proven global experience,” said Francesco Saibene, Project Director for the Ghella Abergeldie JV (GAJV). The technical requirements from the project owner Watercare specified a EPB TBM, and the GAJV, together with Herrenknecht, designed a tailor-made machine with capability to operate at up to 9 bar.

Fig 1. Central interceptor route including Grey Lynn extension

The central interceptor is part of a strategy by Watercare to reduce overflows and improve water quality in the western isthmus of Auckland (Fig 1).

The main interceptor will be excavated at depths of between 15m and 110m and will cross the Manukau Harbour at about 15m below the seabed. “The TBM will bore through well known soil formations, with the possibility of operating in basalt. The cutterhead is therefore designed for operating in both soft ground and hard rock,” said Saibene. “The biggest challenges are likely to be under the Manukau Harbour, potentially experiencing water pressures of up to 9 bar, and then tunnelling under residential Auckland, predominantly under private property, at depths up to 110m.”

Most of the spoil is intended to be reused at Puketutu Island to restore an extinct volcano and create a public park.

Along the route will be 17 shafts reaching depths of up to 80m, and two link sewers of 1.1km long x 2.4m i.d and 3.2km x 2.1m i.d., excavated with two pipe-jacking machines.

Construction work started at the Mangere wastewater treatment plant, to install diaphragm walls for a double shaft, and a shaft at May Road, the second main working site of the project.

“The logistics in the Mangere launch shaft and the May Road shaft are demanding in terms of limited space and depths at up to 69m,” said Saibene.

The TBM is expected to arrive in Auckland at the end of 2020 and will be launched in the first half of 2021 from the Mangere site using both shafts for the launch. Pump station construction in the larger of the double shaft will start once the TBM has advanced about 200m and its operations will be via the inlet shaft alone. The TBM is expected to progress at an average of 16m/day.

The project is programmed to be completed and commissioned in 2025. ■

References

- Preferred contractor selected for Auckland interceptor – *TunnelTalk*, November 2018

TBM order confirmation with Herrenknecht by the Ghella Abergeldie JV

Melbourne West Gate TBMs on hold

Jonathan Rowland, *TunnelTalk*

Contaminated ground holds up launch of West Gate TBMs

The first of two 15.6m diameter Herrenknecht TBMs procured by the CPB Contractors-John Holland JV to excavate the twin tubes of the West Gate highway in Melbourne was assembled and ready to begin excavation on its 4km long drive in mid-2019 after arriving from the Herrenknnecht factory in China in March. The cutterhead, as the last assembly component of the TBM was lifted into the Footscray launch shaft in August 2019. The second mega TBM, which arrived in March 2019 for the second 2.6km twin tube, is also assembled and in the launch shaft ready to go.

Tunnelling by the machines however was yet to begin at the start of 2020, held up following issues with the management of contaminated soil. The ground through which the TBMs will bore is contaminated with carcinogenic chemicals known as per- and polyfluorinated alkyl substances, PFAS.

PFAS have been used for decades in a range of non-stick, water- and fire-repellent and stain resistant products. Recently, the health implications of PFAS exposure have raised concern, as the chemicals resist physical, chemical and biological degradation and are readily leached into groundwater from where they may enter the food chain.

“Historically, PFAS was an unregulated contaminant and was considered fill material,” said Scott Carlton, Chief Executive of Transurban, the client organisation developing the project under a public private partnership with the State Government of Victoria. In a conference call in February 2020, he explained that arrangements have been evolving over the last few years with the result that a spoil management plan for the project is now required by the State EPA, Environmental Protection Authority. “Everyone has been aware of the issue for a long period of time,” said Carlton. “It was discussed in the environment effects statement, EES, and the way the EPA is looking to manage it has been evolving.”

The West Gate Tunnel Project EES was prepared for Transurban by AECOM and geotechnical assessment was undertaken by Golder Associates with GHD engaged as the technical advisor to the State on the project. Design engineering for the CPB-John Holland JV (CPBJH) is by the Aurecon-Jacobs JV.

In its submission to the 2017 EES, the EPA had warned that there were “limited options available in Victoria for managing or disposing of PFAS-impacted waste”.

The challenge for the project is to find a disposal site that can take the PFAS-contaminated muck and in the quantity and at the speed with which it will be produced by the two mega TBMs. “We have been working with the contractor, the EPA and the State to try and find a solution,” said Charlton, but “at the moment, there is no site capable of taking the spoil”.

As a result of the issues, Transurban said in January 2020 that it had received documentation from the CPBJH JV that purported to terminate its contract as it relates to “issues in respect of the presence, classification and disposal of PFAS within the project site”, with the JV agreeing to continue to work on other aspects of its West Gate project contract.

Despite the January notification, Transurban said that, although details of contractual discussion were “a matter for the project parties”, CPBJH is now “working to finalise plans to secure sites for the safe management of tunnel soil.” This was confirmed by the Major Transport Infrastructure Authority of the Victoria State Government, which said in a statement that a tender process to source an appropriate site for disposal of the PFAS-contaminated spoil was being carried out by the project partners. Sites bidding to provide the disposal facility would need to seek relevant planning and EPA approvals, which will set the limit of PFAS that can be stored safely.

Meanwhile, construction has been continuing at the portal locations and on other elements of the project, including the widening of the surface highway, construction of a bridge over the Maribyrnong River and new connections to the city and to the CityLink highway to the south east of the Melbourne city centre (Fig 1).

To date, about AUD$2 billion of the AUD$6.7 billion project has been spent. As a result of the holdup, the expected opening date of the new highway is officially delayed from late 2020 to 2023. ■

References

- Melbourne Westgate highway approved – *TunnelTalk*, December 2017
- Two mega-TBMs for Melbourne highway tunnel – *TunnelTalk*, April 2017

Fig 1. Route of the new West Gate highway

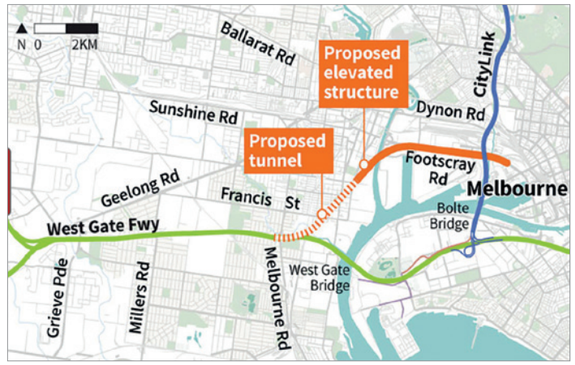
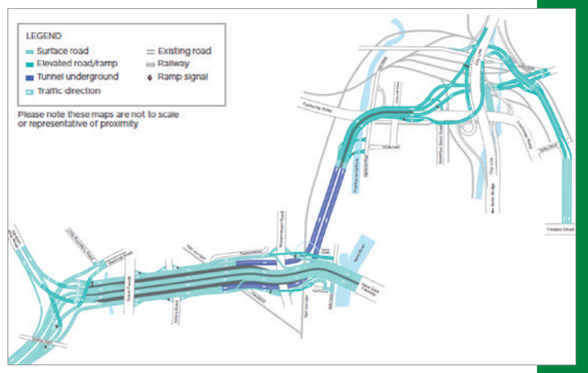


Fig 2. New highway comprises two tubes of 2.8km and 4km long



AUSTRALIA AND NEW ZEALAND

Auckland City Rail Link award

TunnelTalk reporting

Contract C3, the largest for the City Rail Link project in Auckland, is awarded to the Link Alliance, comprising Downer New Zealand, Vinci Construction and Soletanche Bachy, with engineers Aecom, Tonkin & Taylor and WSP Opus. The signing of the alliance agreement with delivery partner CRL Ltd follows a NZ$1 billion increase in the project to NZ$4.4 billion after review of project costs and approval by the New Zealand central Government and Auckland Council of the additional funding.

During final alliance agreement negotiations, Link Alliance began work on NZ$75 million of early works under three separate contracts: at lower Queen Street/ Britomart to convert a terminus station to a through station; under Albert Street in the city centre; and for utility-based work at Mt Eden.

Contract C3 works include:

TBM excavation of 3.4km of parallel 7m diameter running tunnels between Mount Eden Station and Aotea Station, and a fully grade-separated junction within mined caverns connecting with two cut-and-cover tunnels to form east and west facing connections to the existing North Auckland Line.

Aotea Station: A 15m deep, 300m long cut-and-cover station, including platforms, lifts, escalators, service equipment rooms, entrances at Victoria and Wellesley Streets and foundations for an over site development at the Wellesley Street entrance.

Karangahape Station: A 32m deep mined station with entrances at Mercury Lane and Beresford Square, including services, architectural finishes, utilities and foundations for over site development above the Mercury Lane entrance.

Mount Eden Station: A new station to provide interchange between the City Rail Link (CRL) and the existing Western Line including a 7m deep open trench for the CRL platforms and concourse, an entrance at Ruru Street and foundations for over site developments.

When opened in 2024, the project will double the capacity of the rail network in Auckland.

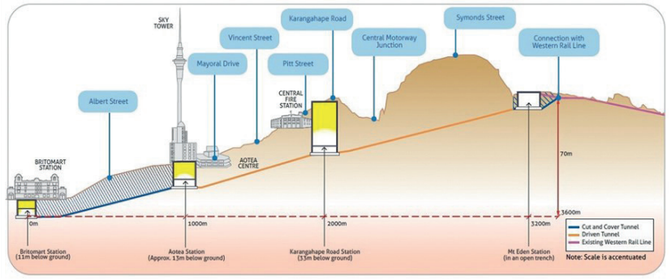
The one competitive tender for the alliance agreement contract was presented by the CPB Contractors, UGL (NZ) JV with engineers Beca, McMillen Jacobs and Jacobs New Zealand. ■

References

- Auckland calls for rail link proposals – *TunnelTalk*, October 2018

Route of the new City Rail Link

Scope of the works in Contract C3



Brisbane Cross River Rail mobilises for construction

TunnelTalk reporting

With the Cross River Rail contract in Brisbane, Queensland, finalised, major contractors moved to mobilise their workforces and to begin construction towards completion by 2024.

Pulse, the consortium selected as the preferred proponent, and comprising the CIMIC Group companies, Pacific Partnerships, CPB Contractors, and UGL, with international partners DIF, BAM, and Ghella, will deliver tunnelling works, new underground stations, and ongoing maintenance services. CPB Contractors, in a joint venture with Ghella and BAM International, will deliver design and construction of the civil works with UGL delivering the mechanical and electrical works and providing maintenance services for 24 years.

The Pulse consortium sponsors and equity providers are Pacific Partnerships (49%), DIF (26%), BAM PPP PGGM (15%), and Ghella Investments and Partnerships (10%) with the Queensland State Government providing an AUD$5.4 billion capital contribution for construction.

The rail network in Brisbane is constrained by a single rail river crossing and all lines run through the same four city centre stations. In addition, demand for passenger rail services is forecast to almost triple by 2036. The Cross River Rail project will unlock the bottleneck into the Brisbane central business district by delivering a second river crossing, allowing more trains to run more often, and integrating with new roads and bus services for more readily accessible public transport across the region.

The Cross River Rail route will integrate with Brisbane Metro services

The Cross River Rail project includes a new 10.2km rail line from Dutton Park to Bowen Hills, including 5.9km of twin tunnels under the Brisbane River and the city centre, plus four new underground stations at Boggo Road, Woolloongabba, Albert Street, and Roma Street.

Albert Street Station will span 294m underground. As the first train station built in the city in more than 120 years, it will be the deepest station on the network at 31m below street level. It is expected to be the busiest of the four new underground stations, with 70,000 passengers projected to use the station every weekday by 2036. Woolloongabba and Roma Street Stations will be 27m below street level and will have 220m long platforms to accommodate nine-car trains for future capacity, while Boggo Road Station will be 19m below street level. The Woolloongabba site will become the staging area for the TBMs and roadheaders before becoming the location of the new underground station. ■

References

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- Australia examines terrific regional workload – *TunnelTalk*, November 2017

Lesotho Phase II dam and tunnel shortlists

TunnelTalk reporting

After attracting a high level of interest for prequalification, six groups, dominated by construction companies from China, are shortlisted to bid for the Polihali dam and the transfer tunnel contracts of the Lesotho Highlands Water Project Phase II.

From 12 groups that prequalified, six have been shortlisted (Table 1) for the 38km long x 5m diameter gravity transfer tunnel that will connect the new reservoir at Polihali with the existing Phase I project reservoir at Katse.

Of eight groups that prequalified for construction of the 165m high concrete-faced rockfill Polihali dam and appurtenant works, six have been shortlisted (Table 2).

Also currently in procurement is award of the geotechnical investigation drilling programmes for the Polihali transfer tunnel alignment and for the proposed lake tap connection of the transfer tunnel into the existing Katse reservoir. Four groups of companies all from South Africa have submitted bids for the contracts.

Progressing in the meantime is drill+blast excavation of the Polihali dam diversion tunnels following award of the Maluti 517 million contract in early 2019 to the SCLC Polihali Diversion JV of Salini Impregilo and CMC di Ravenna of Italy with LSP Construction of Lesotho and CMI Infrastructure of South Africa. The twin 1km long tunnels, one of 7m in diameter and the other of 9m diameter, will divert the river flow around the dam construction site. They will also provide capacity to carry flood waters and the flexibility to work in one tunnel while the river flows in the other. ■

References

- Lesotho appoints experts and calls for prequalifications – *TunnelTalk*, January 2019

Plan of the Polihali Dam and transfer tunnel

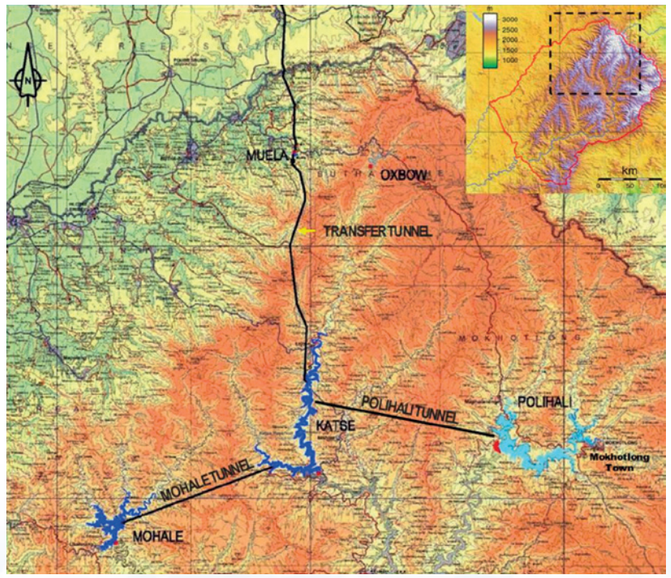


Table 1. Gravity transfer tunnel shortlist

Sinohydro-UMSO-Nthane JV
- Sinohydro Corporation (China)
- UMSO Construction (South Africa)
- Nthane Brothers (Lesotho)

Senqu River JV
- China Communications Construction
- China Gezhouba Group
- Raubex Construction (South Africa)
- ENZA Construction (South Africa)
- Subcontractor: Murray and Roberts Cementation (South Africa)

Polihali Transfer Tunnel MVR JV
- Mota-Engil Construction (South Africa)
- Mota-Engil (Portugal)
- Vinci Construction (France)
- RAZEL - BEC (France)
- Subcontractor: Redpath Mining (South Africa)

Wan Shui JV
- Shanxi Hydraulic Engineering Construction Bureau (China)
- Shanxi Yellow River Water Industry Group Corporation (China)
- Setheo Engineering (South Africa)

CBSL Tunnel JV
- China Railway Group
- China Railway Tunnel Group
- Odebrecht (Brazil)
- Concor Construction (South Africa)

Sunshine Tunnel JV
- Salini Impregilo (Italy)
- Stefanutti Stocks (South Africa)
- AXSYS Projects (South Africa)

Table 2. Polihali dam shortlist

Senqu River JV
- Gezhouba Group (China)
- China Communications Construction Company (CCCC)
- RAUBEX Construction (South Africa)
- ENZA Construction (South Africa)

Mota – Engil Polihali Dam JV
- Led by Mota–Engil (Portugal)

Sinohydro-UMSO-Nthane JV
- Sinohydro Corporation (China)
- UMSO Construction (South Africa)
- Nthane Brothers (Lesotho)

CWE-SCIG-VUMANI JV
- China Water and Electric Corp
- SHANXI Construction Group (China)
- VUMANI Civils CC (South Africa)

CBSL Dam JV
- Odebrecht (Brazil)
- Concor Construction (South Africa)
- China Railway International Group
- China Railway No2 Engineering Group

Sunshine Tunnel JV
- Salini Impregilo (Italy)
- Stefanutti Stocks (South Africa)

Ground freezing assistance under Suez Canal

Ibrahim Raafat, EAAF; Haider Fadhel, CDM-Smith GmbH, Germany; Mina Philips, Arab Consulting Engineer

Excavation of cross passages between the twin tubes of the new highway under the Suez Canal at Ismailia in Egypt have been excavated with the assistance of ground freezing. The freeze supports the sandy and silty soil below the groundwater table and under a hydrostatic head of up to 5 bar.

The 4.8km long x 11.4m i.d. twin tube road tunnel, with two lanes in each, is procured by the Egyptian Government and was excavated using two 13m o.d. Herrenknecht Mixshields. The new highway passes under a main railway line, the old Suez Canal, and the new canal which opened in August 2015. As they progressed, the Mixshields erected 600mm thick x 2m wide rings of segmental lining.

While two of the four cross passages are close to the canals, the design avoids locating any passages directly under the waterways. Segments of heavier reinforcement were erected in the area of the cross passage breakouts and pre-grouting was applied at cross passages to support breakout of the lining and to transfer stresses to the strengthened ground.

Drilling for the freeze pipes was executed according to designs prepared by CDM-Smith Consult, which considered the compliance with the geothermal design and potential deviation of the drill holes (Fig 2). Close monitoring considered whether additional drill holes were required. Dewatering stand-pipes fitted with blow-out preventers were installed and pressure tested to verify the water tightness of the connection. Dewatering pipes would also release ground water in the core, in case of increased water pressure.

Preparation for cross passage breakout and installation of the freeze pipes began once the TBMs passed the cross passage zones. Subject to structural design confirmation, a full circle watertight brine-freezing collar of about 2m thick was established around each cross passage excavation (Fig 1).

Up to 48 freeze pipes were installed to form the freeze collar. Temperature measurement pipes of 3m long were installed along with 6m long dewatering pipes.

The closed circuit freeze system chillers were located inside the tunnel at about 40m from the cross passage breakouts. Temperature measurement pipes were installed from the opposite tunnel.

Freezing technique principles

Ground freezing is based on heat withdrawal from the soil. A close-ended freeze-pipe is placed in the soil and an inner, or supply, pipe is inserted into the freeze pipe. The cooling medium flows through the supply pipe and backs up through the freeze pipe. The heat is exchanged between the soil and the cooling medium. Continuous flow of the cooling medium maintains the watertight ring of ice.

When the ice ring closes, the water inside the ring cannot run off which increases the water pressure in the core and indicates that the freeze has achieved closure. During the freezing process the water pressure is measured by the manometer at the head of the dewatering bore.

It is known that the growth of the freeze collar is homogenous in homogenous soil conditions and those not influenced by tunnel temperatures. Values below -5°C at the outer circumference confirm that the required freeze body thickness of 2m is achieved. Further it must be validated that the average temperature within the freeze body is equal to or colder than Tmin = -10°C.

Assuming that temperatures at the outer design-circumference of the freeze body shall be below -5°C, and under conservative consideration of a simplified linear temperature distribution versus the freeze wall thickness, the minimum temperature at the centerline of the cross passage core has to be equal to or colder than Tmin = -15°C.

At the opposite tunnel, where freeze pipes fall short of touching the opposite tunnel lining, the freeze body has to grow by at least 1.5m to connect to the opposite tunnel. Due to the circular shape of the main tunnel, the -5°C isochrone has to validate the 1.5m connection zone of the freeze body at the opposite tunnel where the shape of the cross passage connection is an ellipse.

It took, on average, about four weeks to install and establish the freeze around each cross passage.

Cross passage excavation

Once the freeze zone met the design criteria, track sewing and core drilling was used to cut out the precast segmental lining and create a 2m wide x 3.5m high breakout.

Sequential excavation of each cross passage advanced in 1m x 19.6m² full face rounds and was supported with a 25cm thick layer of shotcrete reinforced with steel ribs and wire mesh. Excavation progressed at about 1m/day. The primary lining created a natural load-bearing ring, controlled deformation and minimized heat transfer to the frozen body.

The waterproofing system of a geotextile layer of 700gm/m², a double PVC layer of 3mm and 2mm, plus water-stops and injection hoses was installed. The cross passages were then finished to a 3.8m i.d. with a 350mm in-situ concrete lining with reinforced collars at each tunnel. The final lining is designed to ensure water tightness and to carry the permanent load once the freeze thaws.

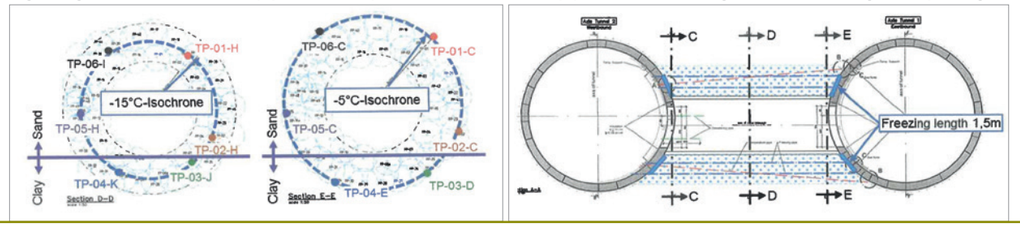
Construction of the cross passages was a considerable achievement for the Ismailia highway project which was scheduled to open to traffic by mid-2019. ■

References

- Breakthroughs for Suez Canal underpasses – *TunnelTalk*, January 2018

From top: Frozen cross passage face; Extra support frame; Breakout of segmental lining

Left: Fig 1. Installation of freeze pipes, dewatering pipes and temperature measurement pipes for the 2m wide freeze collar; Right: Fig 2. Location of freeze pipes and temperature measurement pipes across the length of the 14m long cross passage



Hands on training at Herrenknecht

Open days for potential apprentices

Herrenknecht News Release

The fourth open day at the Herrenknecht workshop in Schwanau, Germany, attracted 350 interested boys and girls from local schools, together with their parents, to look behind the scenes at Herrenknecht.

Pupils visited 15 stations showcasing 13 different options for training in industrial, technical, or commercial areas of the heavy machine manufacturing business. They were offered the chance to make a rose out of metal, design technical drawings, use soldering irons, and explore the inside of a TBM via virtual reality. The highlight of the visit was viewing first hand the rotating cutterhead of a TBM for a metro project.

Pupils were given three options for joining apprenticeships at Herrenknecht while still studying. Current apprentices and training supervisors were on site to answer questions about the application process, the theoretical and practical content of the training occupations, the course of the apprenticeship, and details of degree internship programmes.

"I am personally pleased that the offer to get a taste of our apprenticeships is so well received," said Klaus Himmelsbach, Head of Training at Herrenknecht.

About 150 apprentices, student trainees and degree interns are in training at the Herrenknecht centre in Schwanau annually, making Herrenknecht one of the largest trainers in the region. ■

References

- Refugees among new apprentice intake – *TunnelTalk*, November 2017
- Hands on training – *TunnelTalk*, July 2018

The machine park was of special interest

About 350 young people attended

NATM Course News Release

NATM Master of Engineering programme

Leading the education and accreditation of engineers in the design and construction of NATM (The New Austrian Tunnelling Method) is the programme offered jointly by the Montanuniversität Leoben and TU Graz in Austria. NATM has become a gold standard approach for versatile underground excavation worldwide. As a result, there is a strong and growing demand for engineers with qualifications in this field.

The course, offered by the Institute of Rock Mechanics and Tunnelling at TU Graz and the Institute for Subsurface Engineering at Montanuniversität Leoben, progresses across six semesters and leads to a Master of Engineering, MEng, degree.

The programme, titled NATM Engineering: Construction, Rehabilitation and Operation of NATM and TBM Tunnels, offers the opportunity to study geotechnical engineering and tunnel excavation, as well as both NATM and TBM excavation in detail. Completing the course equips the graduates to design, build and supervise the construction of tunnels, shafts and underground caverns according to the NATM principles.

All parts of the programme are held in English as the language of instruction, and its programme flexibility attracts participants from across the world. To date 65 students from 32 different countries have graduated from the programme with an MEng.

The programme is open to engineers who have entry-level qualifications in

From top: Studying in the art of NATM excavation; All aspects of NATM excavation are covered

construction or mining, and is designed for geotechnical and geological engineers who want to specialise in tunnel construction and NATM engineering in particular.

Applicants must have one of the following qualifications:

- A Masters or Diploma degree from an Austrian or international university;
- An equivalent degree at a third-level educational institution in Austria or other country of the world;
- A Bachelors degree in a relevant subject;
- At least three years of professional experience in a relevant subject area.

The programme is divided into six three-week modules scheduled across three years. This part time programme provides candidates the opportunity to maintain employment while studying for their degree at the same time.

A maximum of 30 students are accepted to each programme cycle.

In addition to university lectures and field trips, the course also has access to the facilities offered by the Zentrum Am Berg, ZAB, research centre operated by the Montanuniversität Leoben. The underground facility provides two parallel road tunnels and two parallel rail tunnels as well as a test tunnel, enabling research, development,and training under realistic 1:1 scale underground conditions.

"The concentration of tunnelling expertise in Austria inspired TU Graz and the Montanuniversität Leoben to offer this programme," said Professor Schubert of TU Graz. "The success of the programme confirms the strong demand for engineers with specialist knowledge in this area." ■

References

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ITACET training courses at the WTC 2019 in Naples

Roland Herr for *TunnelTalk*

Tunnelling 4.0: Information Technology and Communication were the topics of two ITACET training courses at the WTC2019 in Naples.

The two-day course on Information Technology attracted 75 delegates and highlighted the use of BIM (building information modeling) in particular. Professor Markus König of Ruhr University Bochum in Germany explained the fundamentals of BIM and described how BIM allows the visualization of complex situations in order to assess possible risks more accurately. He explained how to use BIM and described the advantages and disadvantages of this technology.

Further topics of the 21 presentations included the use of automation as well as virtual and augmented reality as tools to improve tunnel construction processes; advanced technologies for geotechnical mapping and exploration; surveying and monitoring; and automation applied to underground construction equipment. Karin Bäppler, Head of Business Development Traffic Tunnelling with Herrenknecht, gave an overview of the digitization and networking features applied to TBM technology and in particular of the interaction between machine, cutting tools and prevailing geology for real-time networking of products and processes.

Max Eckstein, Sales Director of shotcrete machinery for Sika Aliva and President of EFNARC, gave insights with Eric Odkrans of Edvirt into robot-assisted sprayed concrete and digital technology for mechanised shotcreting. The industry is working on automatized spraying with self-positioning and thickness control including real-time control of all operational parameters, data recording and transition, preventative maintenance, alternative power sources, and personal safety to achieve total automatisation of the spraying process. This can be realized with different scanning and automatisation technologies using laser, ultrasound, radar, and cameras. Parallel to these developments, EFNARC, founded in 2009 to improve and secure a high skill level among concrete spraying operators and nozzlemen, now offers a virtual training and assessment of nozzlemen, which is in high demand worldwide. A similar development was presented by Nicolas Ziv of Bouygues who introduced the Thalia simulator that uses digital technologies and augmented reality for training TBM operators and workers.

Stakeholder engagement

Whether a tunnel is needed or not sometimes seems of less importance than the acceptance of the project by the public. Communication about major projects has, therefore, become more relevant, with communication to be established at very early stages of project development. The Italian Tunnelling Society (SIG) and the ITACET Foundation picked up this topic for a one day Communications training session that attracted 35 participants.

Virtual training for nozzlemen and simulated TBM operator training is becoming more common

Successful communication can turn public opposition to acceptance of major infrastructure projects

Ten specialists from all parts of a project gave insights about the latest communication techniques and approaches that can be applied to foster interaction amongst stakeholders and within the scope of major underground works projects. My own experience was delivered in a presentation from my point of view as a journalist.

Pietro Jarre and Roberto Mezzalama gave an impressive presentation from a job site's view of communication. In the past, decision-making in regard to development of infrastructure was almost exclusively the domain of architects, engineers, planners and a handful of public authorities. But the general public has increased its influence and is now a major force in determining the success or failure of an infrastructure project. The authors explored some underlying trends and presented some techniques to effectively address the increasing complexity of dealing with a skeptical and often adversarial public.

Antonia Cornaro and Han Admiraal, both of the ITA Committee on Underground Space (ITACUS), focused on the use of new media and social networks in relation to tunnelling and underground space projects. There were presentations also about the communication efforts on mega projects of the world including the Brenner Base Tunnel, the Swiss Alpine base tunnels, the Lyon-Turin railway project, the Alaskan Way viaduct replacement project in Seattle, USA, and a large underground space construction project in South Korea.

Ten years of ITACET training

ITACET, the ITA Committee on Education and Training, has organized about 80 training sessions since its first in 2009, with the numbers of participants ranging from 35 to 400, depending on the venue, the country, the topic of the session, and if the event is associated with an international conference. For the two sessions at the WTC 2019 in Naples, both SIG and ITACET conducted an effective promotion campaign to attract participants.

Hats off to the organisers for high-quality presentations and the selection of topics and to the presenters. But how to increase the number of participants?

Despite a lot of promotional information, the number of participants was too low for such important topics in which the whole industry should be interested. Solutions are needed to attract more participants to the ITACET training sessions.

Training sessions are a must!

I would like to call on all engineers to join these outstanding chances of training and knowledge transfer from specialist presenters from everywhere in the industry. There are many ITACET training events planned in the coming months, including at future World Tunnel Congress events. Future themes of the courses include Innovation in Tunnelling, Geotechnical Engineering, and Project Management. ■

References

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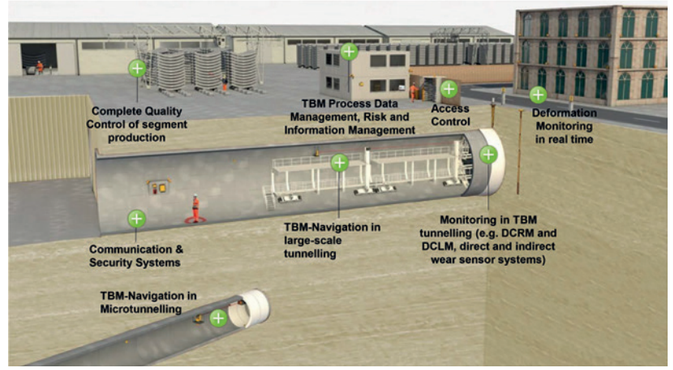
Overview of new technologies for mechanized tunnelling by Karin Bäppler



Skills support for young professionals in the USA

UCA News Release

As the underground construction industry continues to grow, more skilled personnel are needed to bring complex and influential projects to fruition.

To assist this effort, the Young Member Committee of the UCA Underground Construction Association of the USA encourages students and young professionals to gain technical knowledge and leadership skills by providing networking opportunities, specialist seminars and links between universities and industry.

In 2019, the UCA Young Members presented a webinar by Steven Kramer, Senior Vice President of COWI North America, who discussed current trends in procurement and delivery of major tunnel projects in the USA.

Members were encouraged to attend the RETC Conference in Chicago in June where the UCA hosted a Young Members networking event and a scholarship orientation for students who had won bursaries to attend the conference.

The group hosted a series of educational webinars in 2018 and the UCA Young Member Executive Committee of Everett Litton, Demetrio Criscuolo, Ritika Kundu, and Luis Avila welcomed students and young professionals to the North American Tunneling Conference in Washington DC in June 2018, introducing them to the world of underground construction through a presentation and panel discussion.

UCA Young Members networking event

At the end of 2018, the UCA Young Members presented a well attended webinar by Dr Gabriel Walton, Assistant Professor at the Colorado School of Mines, who discussed the influence of the geology on underround excavation projects

At the Cutting Edge Conference in Atlanta in October 2018, the UCA Young Member Committee hosted a session on innovative uses of underground space, emerging tunneling trends and technology, new techniques for renovation and repair projects, and current developments in digital technology and 3D imaging. ■

2019 executives of the UCA Young Member Committee. From left, top: Everett Litton, Demetrio Criscuolo Bottom: Ritika Kundu, Luis Avila

References

- Tunnellers to meet in Washington DC – *TunnelTalk*, June 2018

Training to extend life of water systems

BAMI-I News Release

Training utility personnel on how to implement asset management to extend the life and efficiency of water and wastewater systems is the mission of the Buried Asset Management Institute International (BAMI-I). In 2019, the Institute teamed up with the City of Atlanta Department of Watershed Management to offer a four-day workshop. Participants of the Certificate of Training in Asset Management (CTAM) program received Associate Water Asset Manager designation.

BAMI-I created the CTAM program in 2008. It is usually offered online and so far individuals from 16 countries have enrolled.

Offering water asset management training worldwide

"The principles and practices of asset management apply to all networks. About 80% of water pipelines are 6ft-12ft (1.8m-3.7m) in diameter," said Professor Tom Iseley, Chair of the BAMI-I Board of Directors. "The CTAM course covers all underground water assets and was developed by industry professionals for water utility decision makers, such as managers, supervisors, crew leaders, consulting engineers and service providers."

The four modules of the program are:

- Overview of asset management.
- Developing an asset management program.
- Managing an asset management program.
- Financing an asset management program. ■

References

- Tight squeeze for Singapore sewer drives – *TunnelTalk*, November 2018
- Final push for cleaner waterway in Washington DC – *TunnelTalk*, July 2018

Studying TBMs in Turin

TunnelTalk reporting

Now running for more than 12 years, the Specialising Masters Programme in Tunnelling and TBMs at the Politecnico di Torino, Italy, provides the basis for a career in the tunnelling sector. The programme is designed for students who have already completed a Masters Degree in civil or environmental engineering or geology.

The course combines academic teaching with lectures and presentations by industry experts from construction companies, equipment manufacturers, and design engineering firms. It includes nine teaching modules, an internship, and a final project, and is completed in seven months.

Modules include:

- Tunnel design and construction methods
- Rock mass characterisation, geo-investigations, and risk assessment
- Tunnel supports
- Numerical design
- Mechanised tunnelling and hard rock TBMs
- Soil mechanics
- Plants and microtunnelling

Politecnico di Torino, Italy

- Contractual and legal aspects of tunnelling, site management, and quality control
- Safety and environmental issues at work sites

The course is delivered in English at the Politecnico di Torino Lingotto Campus.

Graduates go on to careers at design firms, construction companies, and suppliers of tunnelling tools and equipment. Endorsed by the ITACET Foundation for Education and Training on Tunnelling and Underground Space and the Italian Tunnelling Society, the course has recevied support from the organisations developing the Tunnel Euralpin high-speed rail link between Lyon and Turin and the Brenner Base railway tunnel between Austria and Italy. ■

References

- ITA focus on skilling future tunnellers – *TunnelTalk*, October 2017

New CEO and SmartDrive developments for Normet

TunnelTalk reporting

An Australian citizen, Ed Santamaria, was appointed as the new President and CEO of the Normet Group in June 2019. Taking over from interim President and CEO Aaro Cantell, Santamaria will be based in the Normet Espoo office in Finland and started in his new role in November.

Ed Santamaria, CEO, Normet

Santamaria, who has an MBA degree, brings to the position a wealth of experience of the mining industry and from his previous role as President of the Parts and Services Division at Sandvik Mining & Rock Technology. He has spent in total 13 years in different management roles within Sandvik and spent the previous 20 years with SDS Corporation, a designer and manufacturer of drilling equipment, which was acquired by Sandvik in 2006.

"Ed knows well how to lead people in this kind of a global matrix organisation," said Cantell, who is also Chairman of the Normet Group. "I believe he can help us find areas to improve our operational efficiency as well as help identify new growth areas."

"Joining an entrepreneurial and agile company with a global reach is an opportunity for me," said Santamaria. "Using my experience and my MBA credentials, I can contribute to the further development of the Normet business both within the tunnelling and mining sectors."

News of the new CEO announcement came after Normet reported a strong year of growth and profitability for fiscal year 2018. Turnover grew by 21% to €315 million and earnings, before depreciations and amortizations, reached €38 million, almost double that of 2017. The Normet Equipment and Services businesses achieved the strongest growth while the Ground Control and Construction Technology division declined modestly compared to 2017.

"The outlook for year 2019 is still positive, although the market growth is slowing down," summarized Aaro Cantell. "We are in the process of scanning new growth areas to secure our renewal and future growth. Our aim is to identify and launch two to four of these growth initiatives during 2019-2020."

An important launch for the company in 2019 was the Normet SmartDrive technologies for sustainable and green underground civil works and investments. Another is its investment in expansion of its factory in Iisalmi, Finland.

SmartDrive, is a fully electric, battery-operated and totally emission-free range of equipment that saves costs at the same time. With the SmartDrive launch, Normet also introduced its SmartScan 3D laser scanning technology which is the next step towards fully automated concrete spraying technology. SmartSpray increases the automation level of the spraying process, and SmartScan is a system to measure concrete layer thickness to improve quality control, inspection and reporting.

A new safe and efficient concrete spraying machine for the most confined places was also launched in 2019. Agile yet powerful, the Minimec is used in areas of limited access, such as cross passages, shaft excavations and small adits, and outperforms nozzleman handheld spraying in safety, reach and productivity.

Despite its small size, Minimec can apply the full capacity of the spraying pump, improving process performance. For increased safety and user comfort, the machine has a remote driving system, which allows the operator to drive and spray from a safe distance.

To accommodate the manufacture of the new SmartDrive range of equipment, Normet is investing in its lisalmi factory to build a new digital testing center, expand the production capability and invest into production automation. Demand for fully-electric machines is expected to grow significantly.

In early 2020, and to better support customers in South America, Normet opened a new service centre in Chile. The new centre will also provide equipment rebuilds and process training.

"The service centre will enhance our capability to deliver refurbished machines and help train technicians of our customers to improve the competence of their staff on key processes," said Juan Albanece, General Manager, Services for Normet South America. "For example, with sprayed concrete we have proven that training will improve productivity, reduce rebound and reduce CO_2 emissions."

Normet, with its broad offering of underground mining and tunnelling equipment, construction chemicals, rock reinforcement products and services, currently employs more than 1,200 business professionals from its headquarters in Finland to its global operations in more than 50 bases in 30 countries. ■

References

- New facility in India and greater customer focus – *TunnelTalk*, May 2018
- Improved concrete spraying and explosive charging – *TunnelTalk*, July 2017

The SmartDrive range of fully electric, battery-operated and emission-free Normet equipment

From left: Compact shotcreting; Investment will expand the factory at Iisalmi; New service centre in Chile

Latest equipment advances on show at *bauma* Munich

TunnelTalk reporting

Convened on the vast show grounds of the Messe München in Germany, the *bauma* trade fair of 2019 covered more than 600,000m² of exhibition space including 18 halls of 200,000m² space and 414,000m² of open air exhibition space. More than 3,700 exhibitors presented their products to more than 600,000 visitors with many more waiting for a space to become an exhibitor.

Among the significant themes of the show was digitisation and efficiency, both of them targeting higher productively as an end goal. Within the tunnelling sector, all the main *TunnelTalk* industry partners were represented including a higher number of Chinese companies, some exhibiting for the first time. ■

Table 1. Top exhibitor countries	
Germany	1,269
Italy	549
China	401
Turkey	189
UK	133
USA	126
France	120
Netherlands	116
Spain	96
Austria	91
Finland	56

References

- bauma China 2018 – China manufacturing on show – *TunnelTalk*, December 2018
- bauma Conexpo India 2018 – *TunnelTalk*, December 2018
- bauma 2016 - Tunnelling attractions at the world's trade fair – *TunnelTalk*, April 2016

As a full-range supplier of mechanised tunnelling technology, the **Herrenknecht** stand presented its journey in tunnelling. Through an impressive set of interactive screens, videos and graphics, Herrenknecht described how its focus is on making the tunnelling process faster and more efficient. A particular display illustrated an almost continuous single shield TBM operation with the segments erected one at a time as the forward thrust is applied to the previous ring segments. Counter-intuitively, the concept demonstrates higher progress with narrower segments rather than the wider 2m+ rings used commonly with current single shield TBMs where excavation stops while the ring of segmental lining is erected.

Herrenknecht was also celebrating its presentation of the coveted *bauma* Innovation Award 2019 in the machine category for its innovative E-Power Pipe® installation method. Developed in cooperation with Amprion GmbH and RWTH Aachen University, the centre piece of the method is the newly developed AVNS350XB micro machine with an excavation diameter of 505mm and a jet pump for handling excavated material. Jet pumping of excavated material allows drives up to 10 times longer than previously in the small diameter range. Drives of more than 1,000m and at shallow installation depths of 1.5m are possible with the E-Power Pipe technology.

The system has been developed as a more environmentally friendly alternative to long distance pylons to bring high voltage electricity cables from the wind farm installations in the North Sea to the high electricity demand powerhouses in Southern Germany. The AVNS350XB machine excavates the pilot bore with fully fitted service pipes installed from behind using the Herrenkencht Direct Pipe technology. The service pipes are then retrieved, to be used again on the next drive, as a conduit pipe is pulled in from the front. Once installed the high voltage power cable is pulled through – each drive being 1,000m long to match the supply reels of cabling.

Herrenknecht E-Power Pipe a 2019 bauma Innovation Award winner

Celebrating 30 years service in the tunnelling field, **Condat** displayed its full product range at *bauma* – from TBM tail seal and main bearing greases, fire resistant hydraulic fluids, main bearing sealing products, foaming agents and polymers, additives for filling grouts, additives for ground consolidation and many others.

Landmark tunnelling projects for Condat across its 30 years in business include its very first, the Channel Tunnel between Britain and France; the Groenehart project in the Netherlands; and the Port of Miami and Seattle SR 99 highway TBM tunnels in the USA. As a leader in TBM specific products, Condat offers certified products with proven technical benefits including fire resistance and self-extinguishing properties.

Condat is one of the few to design and produce its main range of products, mastering the whole process from R&D and raw materials to the finished product, ensuring consistent and reliable product quality. In 2010, it upgraded its top-selling range of products to meet biodegradable OECD 301 standards to reduce the impact of products on the environment and on the excavated soil. To further this, Condat recently developed a new grease for TBM main bearings. Fully biodegradable and molybden free, BTG 4602 has been approved by Herrenknecht after a joint program of validation. Launched in 2018, BTG 4602 is being used on several TBMs including those working on the Grand Paris Express Metro projects in France. Condat can also supply study and risk assessment of its product toxicology to demonstrate no relevant risks for either the environment or human health.

Condat products on vital TBM operation duty

For all-round digitalisation of pumping technology on construction sites, manufacturer **Tsurumi** presented its smart controller solution that integrates water pumps electronically to make operations as efficient as possible.

"Casing, motors, impellers - the time when components like these were solely responsible for dewatering appears to be over," said Daniel Weippert, Managing Director of the Düsseldorf base of the Japanese pump manufacturer in Germany. The company used its *bauma* exhibition booth to demonstrate how pumps can be integrated into the digital network of the construction world.

Tsurumi Connect is a multifunctional solution that marks the start of the new era. A small hardware box is connected to the pump via the motor protection plug or a control cabinet. It records and analyses the rated flows, controls the aggregate automatically on request and also prevents wrong direction of rotation or over-current. The box is connected to the Tsurumi Connect Cloud via mobile telephone, WiFi or LAN, either permanently, for special situations, or as a result of an alarm. In case the connection fails, the box is able to record data in an offline mode for 30 days.

The system is not a proprietary manufacturer solution. "Tsurumi Connect is able to monitor and control any electrical consumer," said Weippert. It is possible for data of various sensors to be recorded, analysed and taken into account by the control logic. "Configuration is easy and it is not necessary to have a separate SIM card for the mobile phone," explained developers Stefan Himmelsbach and Andre Conraths. Complex applications can be realised and, for the accountants in the head office, invoices can be generated, maintenance intervals can be planned, and failure costs reduced to a minimum. Field test with up to 70 devices connected are planned to conclude at the end of the year and deliveries of the system, developed and produced in line with German standards, started at the beginning of 2020.

Tsurumi Connect links electrical devices on site and an app (right) for control and analysis is included

At its stand, **Normet** introduced its SmartSpray SmartDrive semi-automated concrete spraying machine. "This is the next step in the journey towards our end goal of fully automated shotcreting in civil and mining applications," explained Mark Ryan, Vice President Equipment Offering and R&D at Normet. "When co-ordinates are entered, the SmartSpray machine will complete a spraying cycle automatically with the operator controlling just the angle of the nozzle. Ultimately, our aim is to have spraying machines operating underground fully independently of operators."

The new SmartDrive Spraymec 8100 unit on display on the stand also featured a 100% electric battery drive with the laser scanner unit that assists the semi-automatic operation. The machine is plugged into the main electric power supply for the spraying operation, which at the same time recharges the on-board battery to provide electric tramming for up to 15km before needing a recharge.

From top: SmartSpray SmartDrive shotcreting from Normet; Part of the range of new SmartDrive machines

As a major exhibitor at the *bauma* China trade shows in Shanghai, Chinese tunnelling equipment manufacturer **CRCHI** was exhibiting at *bauma* Munich for the first time. Discussions with the team were about the extraordinary lengths of civil underground excavation achieved in China each year. Confirmation was that CRCHI manufactured 145 TBMs last year in the range from 0.5m to 13m diameter with most in the 6-10m range. CRCHI is the manufacturing arm of Chinese construction company CRCC, one of the top three general construction companies in the world. CRCC completes more than 2,000km of tunnel infrastructure per year and has about 6,000km of tunnelling work currently under construction.

As well as TBMs, CRCHI also manufactures drilling jumbos which are supplied to Chinese contractors to contribute to the 10,000km of tunnelling completed in China per year.

An interesting point made by CRCHI Chairman Liu Feixiang is that 90% of tunnelling in China is by drill+blast and open face methods with the remainder by TBMs.

Liu Feixiang headed CRCHI for the first time at bauma *Munich*

As an example, Liu explained that some 85% of an 800km railway connection to Tibet from Chengdu will be in double-track single-tube drill+blast tunnels. He added that several of the company's TBMs are used in the coal mining industry in China to create the connecting roadways between levels of existing mines. These are often steep inclined drives of up to 45 degrees and more.

For **Brokk**, the launch at *bauma* was of its Brokk 70 hydraulic breaker machine which offers 100% more power then its predecessor and the latest Brokk SmartPower™ technology.

The SmartPower™ electric powertrain increases the unit's power from 5.5kW to 9.8kW and enables the demolition robot to power twice the size breaker as the Brokk 60, providing smoother, more precise movements of the heavier and more powerful attachments. The Brokk 70 comes with several brand new attachments including the new BDC40 drum cutter that brings real cutting power to the smallest segment of demolition robots, and the G32 demolition grapple, as the tool of choice for more efficient soft demolition.

Double power breaking from Brokk

Mining Equipment and Bauer MAT buy Mühlhäuser assets

TunnelTalk reporting

After initiating insolvency proceedings in June 2019, the status of Mühlhäuser company assets became clearer with acquisition of separate divisions. Mining Equipment of the USA has acquired unspecified elements of the company and in December 2019 Bauer Group confirmed its buyout of the subsidiary Mühlhäuser-Obermann.

With acquisition of Mühlhäuser locomotive, rolling stock and ventilation equipment divisions, Mining Equipment aims to build a presence in the European market. "We are ready to build a reputation in the European market," said Mining Equipment Co-President Matt Pope. "This is a great opportunity to do what we do best in a new market and to prove ourselves to new customers, one project at a time." Terms and value of the acquisition are undisclosed.

The deal establishes the first European office for Mining Equipment in Breuberg, Germany, about 50km south of Frankfurt. Paul Zeder and Marco Langnickle are hired from Mühlhäuser to lead the European operations.

Mühlhäuser, with a 110 year history, is a recognised innovator and supplier of rail-bound and trackless transportation equipment, and equipment for concrete, grout and related applications. Mühlhäuser innovations include the one side self-discharger and the rota-dump muck cars, both of which have been used on projects around the world. With its rolling stock and ventilation interests, Mining Equipment also has a large inventory of mine hoists and stage winches used in shaft construction.

The Bauer Group acquisition of Mühlhäuser-Obermann will operate in future

From top: Mining Equipment loco and muck cars in action; Mühlhäuser operations on the Channel Tunnel

under the name Obermann MAT. Mühlhäuser acquired the Obermann portfolio of injection and grouting technology in January 2015. "The company will stay in Michelstadt and 15 new colleagues will join the Bauer Group," said Alexander Konz, Branch Manager of Bauer MAT Slurry Handling Systems, a subsidiary of Bauer Maschinen.

Bauer MAT Slurry Handling Systems was formed in April 2008 when MAT Mixing Plant Technology was incorporated into Bauer Machinery GmbH.

In August 2019 it was reported that SMT Scharf was considering the acquisition of Mühlhäuser-Obermann, alongside its sister company Karl H Mühlhäuser GmbH & Co KG. There had been a co-operation agreement between SMT Scharf and Mühlhäuser since 2016. The agreement covered a logistics solution, developed by the two companies and based on the SMT monorail system. Under the deal, SMT Scharf supplied the major elements of the transport equipment, while Mühlhäuser advised customers, designed tunnel-specific solutions, and managed sales and service. The takeover, however, was dependent on the results of insolvency proceedings and in October SMT Scharf announced that after an assessment, it would no longer be pursuing the acquisition.

It is not known how ownership by Mühlhäuser of the NFM TBM business since February 2019 is to be resolved. It is known that no part of NFM is part of the deal with Bauer MAT or with Mining Equipment, leaving NFM and its future in limbo.

Mühlhäuser acquired French TBM manufacturer NFM Technologies in February 2019. NFM had been in financial difficulty since the insolvency of its principal shareholder, NHI Heavy Industries of China, in 2016. The Mühlhäuser acquisition comprised the NFM brand, the intellectual property, the manufacturing plant at Le Creusot, the stock of components and a staff of 82 people. As a separate undertaking NFM Technologies made 15 buy-back TBMs available for resale and appointed KPMG to assist in the sale of these machines.

NFM machines are currently working on the Semmering Baseline railway tunnel project in Austria, the Tideway sewer project in London, UK, the Paris Metro in France and the Lyon-Turin high speed railway project between France and Italy. ■

References

- Mühlhäuser expands into tunnel lining sector – *TunnelTalk*, 13 January 2015
- New merger for Bauer and MAT – *TunnelTalk*, April 2018
- NFM for sale from insolvent Chinese owner – *TunnelTalk*, 20 September 2018

Top political visit to Herrenknecht

Herrenknecht News Release

German Chancellor Angela Merkel visited the Herrenknecht headquarters in Schwanau in October 2019, affirming her support of the company and its innovations being used on projects around the world, which "really are projects that go down in history," the Chancellor declared.

On a tour of the factory, company founder and Chairman of the Board Martin Herrenknecht showed the Chancellor the tunnelling technology developed and manufactured by the company to enable challenging projects. She praised the innovation of the company and its ability to respond rapidly to new market demands.

The Chancellor also visited the training workshop, giving the more than 100 apprentices present the opportunity to speak with her in person. Following the tour, the Chancellor spoke to 200 invited guests and media representatives and addressed topics such as the shortage of skilled workers, the acceleration of public planning and approval procedures, as well as investments in research and innovation. In her address, the Chancellor spoke of the immense changes that have taken place within a single generation. "This is down to the fact that there are always people who believe you can change the world, that there are people who have an incredible amount of technological ideas who try things out, put them into action and then see that progress really is being made," she said.

Martin Herrenknecht emphasised the importance of the active backing of the Chancellor and the German Government in the current challenging market and competitive conditions for family-run businesses, SMEs, the region, and the more than 5,000 Herrenknecht employees. ■

References

- State visit to Herrenknecht China – *TunnelTalk*, February 2012

From left: Martin Herrenknecht welcomes Chancellor Angela Merkel; Learning about a new method for trenchless installation of cables; With one of the 19 Herrenknecht TBMs for the Grand Paris Express project

Italian construction consolidation

Patrick Reynolds for *TunnelTalk*

Investor and court approvals helped move forward the merger of Salini Impregilo and Astaldi through the Progetto Italia initiative, which aims to form an internationally competitive Italian construction conglomerate. Salini Impregilo has already acquired Cossi, GLF, and Seli Overseas.

The merger was subject to creditor approvals in February and March 2020.

In addition to the planned Astaldi merger, Salini Impregilo gained control of Italian tunnelling specialist Seli Overseas in late 2018. In early 2019, it bought a majority 63.5% stake in Cossi Costruzioni SpA.

Salini Impregilo was itself formed by a merger in 2013 when Salini acquired the bigger Impregilo business. In other changes to the Italian construction sector, the long-standing TBM and tunnelling business, Seli SpA, was restructured in 2015 into three separate companies: Seli Technology, Seli Tunneling Denmark, and Seli Overseas. Salini Impregilo later bought Seli Tunneling Denmark, both firms working together on the Copenhagen Cityringen Metro. Since late 2018, Seli Overseas has been controlled through the Seli Tunneling Denmark business.

Pietro Salini, CEO Salini Impregilo, warns of difficulties in the construction sector

The merger rescues Astaldi from financial difficulties and is part of the Progetto Italia plan by Salini Impregilo to create a major Italian construction group capable of pursuing infrastructure projects of more than €250 million in value. The aim is to compete against large French and Spanish groups, *TunnelTalk* was told. The Progetto Italia initiative consolides the domestic Italian construction sector, which is facing economic and financial pressures (Fig 1).

Progetto Italia aims to create a global EPC company with revenues of about €12–€14 billion, an order book of more than €60 billion, and an employee base of more than 45,000, with most parties, including banks, taking equity stakes in debt-for-equity swaps.

Underground infrastructure is to remain a core of the merged business.

Astaldi declared insolvency in the Italian courts in September 2018. The start of troubles began in its 2017 financial results with payment delays in Venezuela.

Astaldi had previously sold its stakes in the Milan Metro Line 5, the Chacayes hydro project in Chile, and the Third Bosphorus bridge and in the Gebze-Orhangazi-Izmir highway in Turkey.

"In the infrastructure sector, the key to competing globally is size," said Salini Impregilo CEO, Pietro Salini. In a keynote speech at the World Tunnel Congress in Naples in May 2018, he warned that, "New players must be big enough to be able to obtain an investment grade rating and seize opportunities in global alliances. In size, we are talking revenues of more than €10 billion." ■

References

- Consolidation of Italian construction contractors – *TunnelTalk*, July 2019

Fig 1. Recent media reports indicated fragility of companies in the Italian construction industry

Le difficoltà delle aziende italiane

Le prime 20 imprese di costruzioni per fatturato (milioni €)

	Azienda		Fatturato 2016	Dipendenti
1	Salini Impregilo		6.125	30.998
2	Astaldi	Concordato preventivo	3.004	10.866
3	Condotte	Amministrazione straordinaria	1.315	5.854
4	CMC	Richiesta di concordato con riserva	1.063	7.327
5	Rizzani		918	3.615
6	Bonatti		798	4.317
7	Pizzarotti		780	1.243
8	Itinera		700	1.263
9	Ghella		620	1.727
10	Trevi	Difficoltà finanziarie	617	6.089
11	Cimolai		539	1.214
12	Sicim		513	4.420
13	Grandi Lavori Fincosit	Concordato in bianco	457	1.108
14	GCF		358	720
15	ICM		340	1.182
16	Unieco	Liquidazione coatta amministrativa	273	398
17	Salcef		268	738
18	Colombo costruzioni		195	183
19	Renco		187	410
20	Mantovani	Domanda di concordato in continuità	185	370

Fonte: elaborazione del Corriere della Sera

Bekaert buys out Maccaferri partnership share

TunnelTalk reporting

Five years after announcing the sales partnership, Bekaert concluded buyout of the 50% Maccaferri share in the Bekaert Maccaferri Underground Solutions (BMUS) enterprise. From January 2020, the Underground Solutions team works under the Bekaert name alone.

For staff and customers, it has been confirmed as business as usual with no difference in the service level of providing and supplying the BMUS range of Dramix®, Duomix® and Synmix® products.

The current team of engineers and employees in the underground solutions division will continue to offer customers technical guidance and support in the application of fibre reinforced concrete in underground projects, including in shotcrete and precast segment linings.

With conclusion of the buyout, the Underground Solutions division became a wholly owned division of Bekaert, the global producer and supplier of steel wire and coating technologies. Headquartered in Belgium, the publicly traded company has 29,000 employees worldwide and is listed on the Euronext stock exchange in Brussels, with a reported combined revenue of €5 billion. ■

References

- Bekaert + Maccaferri form sales partnership – *TunnelTalk*, June 2014

Keller merges subsidiaries in North America

Jonathan Rowland, *TunnelTalk*

Global geotechnical contractor Keller merged its construction subsidiaries in North America. The merger includes ground-freezing specialist Moretrench, which was acquired in 2018 by Keller group company Hayward Baker. From 1 January 2020, Hayward Baker and Moretrench integrated with other Keller subsidiaries, Bencor, Case Atlantic, Case Foundation, HJ Foundation, Keller Canada, and McKinney, into one operating company.

Founded in 1860 in the UK, Keller has operations in more than 40 countries across six continents. The company has been active in North America for more than 70 years and currently operates from 50 offices in the USA and Canada. The region is the biggest market for the company, accounting for about half of the total group revenue of £2.2 billion in 2018. Operating profit from its North American operations totalled £78.6 million in 2018, an increase of 3% on the year before.

The integrated company will be managed as eight business units. Seven of these will be based geographically across North America, offering a full range of products.

"Operating as one company will make the Keller group companies easier to understand and engage with," said James Hind, President of Keller North America. Under the new structure, "customers can be confident they are getting the best, most competitive solutions, especially when these involve multiple techniques."

The eighth business unit will offer speciality products, such as diaphragm walls, speciality grouting, ground freezing, and dewatering. GEO-Instruments, the instrumentation and monitoring subsidiary, will remain a separate brand. ■

James Hind will lead the merged company

References

- Keller-Hayward Baker buys Moretrench – *TunnelTalk*, April 2018

Recipients of the 2019 ITA Awards

TunnelTalk reporting

2019 ITA Award celebrations

Projects of complex design and construction, and developments of outstanding achievement in the fields of industry safety and innovation, were selected as the best of the best and recipients of the 2019 ITA Awards Brunel Trophy. At the end of the day-long conference, during which the Award finalists in each of eight categories provided details of their projects, the winners were announced at the gala dinner in Miami, USA.

Major Project of the Year with a budget of more than €500 million Presented to the Tuen Mun-Chek Lap Kok subsea highway link in Hong Kong. The 4.5km long twin-tube subsea tunnel was constructed using two Herrenknecht slurry Mixshield TBMs at up to 55m below sea level and under hydrostatic pressures of up to 5 bar. The first 630m of the first TBM drive was excavated using a 17.63m diameter shield, for a three lane roadway for the up-gradient exit for the highway, with the machine rebuilt and reconfigured into a 14m diameter shield to continue a two lane roadway. As an alternative to ground freezing, a mini TBM was developed to excavate 41 subsea cross passages between the parallel highway tubes.

- **Client**: Highways Department of the Government of Hong Kong
- **Contractors**: Dragages-Bouygues JV
- **Engineering firms**: AECOM, ARUP, Atkins and Golder

Fellow category finalists were:

- The Follo Line railway tunnel, Norway
- The Seoul metropolitan high-speed railway Yulhyeon tunnel, South Korea
- The road and metro Sanyang tunnel under the Yangtze River in Wuhan, China

Project of the Year with a budget between €50 million and €500 million Awarded to the estimated USD$1.2 billion Regional Connector project for the Los Angeles Metro in California, the design-build procurement of the 1.9 mile underground light rail system, with three new underground stations, included twin tubes excavated using a TBM on tight curves, an open cut section to deal with tie back anchors supporting the basements of existing buildings, and an SEM alternative to open cut for a crossover cavern.

- **Client**: Los Angeles County Metropolitan Transportation Authority (LA Metro)
- **Contractors**: Skanska-Traylor JV

Fellow finalists were:

- Toluca suburban railway, Mexico
- Badaling tunnel and Great Wall Station on the Beijing-Zhangjiakou high-speed railway, China
- Sha Tin to Central metro immersed tube link, Hong Kong
- Ulriken TBM railway tunnel, Norway
- Victory Boogie Woogie highway tunnel, The Netherlands

Safety Initiative of the Year Awarded to the Air Quality Working Group of the Australian Tunnelling Society (ATS) for its industry-first collaboration on research and control of silica dust in underground excavation environments. Silica dust is a major health issue for the Australian tunnelling industry. During a 12-month period, the stakeholders of ATS took a proactive approach to controlling silica dust and producing a much-needed body of reference material available on the ATS website for free download and sharing.

Fellow finalists of the category were:

- An automatic geological-prospecting technique for TBM tunnelling, China
- Robotisation of the tubular steel arch installation, Italy

Technical Product or Equipment Innovation of the Year A project, developed in Malaysia, for autonomous operation of TBMs using artificial intelligence algorithms for the autonomous operation of multimode TBMs working on Line 2 of the Kuala Lumpur Klang Valley MRT. The system is installed on an industrial PC module to assess the thousands of data points sampled every minute by the more than 400 sensors on the TBMs. A computer processes these data points and responds instantaneously with appropriate decisions, much faster than human operators. The system has been successfully used to completed urban tunnelling in complex geologies and to undercross live rail lines and a 14-lane highway.

Other finalists in the category were:

- ARCHITA, a multi-dimensional mobile mapping system, Italy
- AXON, wireless connectivity for tracking personnel and equipment, monitoring the environment and integrating with other systems including pumps and ventilation fans, Australia
- Tunnel inspection and maintenance using artificial intelligence, Switzerland

Technical Project Innovation of the Year Extension of three existing Toulouse Line A underground metro stations in France, the project required the removal of the existing station tunnel linings, while keeping the subway in operation and minimising, as much as possible, the disturbance caused by the works in the urban environment.

- **Client**: Tisséo Ingénierie
- **Contractors**: Eiffage Genie Civil/I. CO.P/BG Ingénieurs Conseil / Forézienne d'entreprises/Fontanié
- **Engineering firms**: Arcadis/Puig Pujol Associés/Betem

Other finalists:

- Single-tube double-line rectangular shield technology system, China
- Intersecting and overlapping tunnel construction for the Tianjin Metro Lines 5 and 6, Lot 1, China
- Construction of a large cross-section in extremely gassy conditions, China

The Project of the Year with a budget up to €50 million Modernisation of the Vladivostok railway tunnel in Russia. Water seepage was a major problem for the 1.4km long single-track railway tunnel built 82 years ago, with more than 1,800m³ of ice being cut from the tunnel each winter. The upgrade required casting of a new multi-layer drained lining.

Other finalists:

- Finsbury Park Station step-free access upgrade in London, UK
- Outram Park metro station connection, Thomson Line, Singapore

From left: MMC-Gamuda team receives Technical Initiative Award for autonomous TBM operating system; Kate Cole of the ATS Working Group accepts the Safety Initiative Award; Regional Connector achievements including first SEM cavern in Los Angeles

Innovative Underground Space Concept of the Year Awarded to an underground green farming concept developed by the Swiss Center for Applied Underground Technologies (SCAUT). Underground green farming offers the opportunity to produce food locally in urban areas and to produce several harvests per year. The underground space offers other major advantages including constant climate conditions and protection from natural climate variations.

Other finalists in the category were:

- Prefabricated urban underground parking spaces using small TBMs, China.
- Southern Nevada Water Authority low level intake pumping station, USA. ■

References

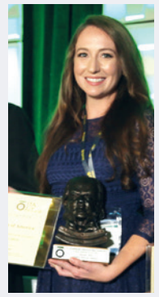
- Winners of the 2018 ITA Awards – *TunnelTalk*, November 2018

ITA Lifetime Achievement Award

Past ITA President Tarcisio Celestino presents award to Harvey Parker, joined by his wife and ITA travel partner Karen

The 2019 award honours the career of Dr Harvey Parker. With more than 45 years of experience in the tunnelling industry, Dr Parker is a University of Illinois Urbana-Champaign alumnus, where he received his PhD in Civil Engineering with a Minor in Geology, and is the author or co-author of more than 60 publications, often on planning, risk management, and geotechnical investigations. The many projects he has been involved with include the Alaskan Way viaduct replacement highway tunnel project in Seattle, the metro system in Los Angeles, and the inception of the metro system in Washington DC.

Young Tunneller of the Year



Amanda Kerr, aspiring tunneller

Amanda Kerr of the USA was selected as the from among fellow candidates from Singapore, Switzerland, China and Japan. Amanda received a Bachelor of Science in Engineering in Civil Engineering and a Master of Science in Engineering in Construction Engineering from the Arizona State University in Phoenix and began her tunnelling career as a leading engineer on the Northgate Link metro extension in Seattle with Michels-Jaydee-Coluccio. She has been involved in TBM design and hardware selection; has led a team of engineers managing construction of eleven shafts; served as lead project scheduler; has overseen structural design modifications that reduced construction costs and saved more than 180 calendar days; and negotiated project change orders with the client, preventing any outstanding claims.

Canada honours global input to its national fabric

TunnelTalk reporting

Through history, nations have relied on the skills and labour of immigrants and internationals to build their infrastructure. Canada recognised both in its 2019 Tunnelling Association of Canada TAC Awards.

Presented during a gala dinner at a symposium in Winnipeg, Manitoba, engineers from around the world and their innovations were recognised for their contributions to building the nation.

In a deserving tribute, TAC honoured Enrique Fernández González of Spain with a posthumous Lifetime Achievement Award after a fatal accident in his home town near Madrid. González, of Dragados and its engineering division gGravity, began the association with Canada at the start of the Eglinton LRT project in Toronto on which Dragados was involved on contracts for both TBM running tunnels and station construction. González is recognised for other major underground infrastructure projects in Canada including the current Ottawa and Montreal LRT projects.

The 2019 Innovation Initiative of the Year Award was presented to the design of the Lyon and Parliament underground stations of the Confederation Line of the Ottawa Metro designed by Dr Sauer & Partners in collaboration with gGravity Engineering and built by the Dragados/SNC-Lavalin/OLRT/EllisDon JV. Permanent tensioned tie rods across the span of mined underground stations under shallow cover were installed to take the load and transfer it away from the walls of adjacent high rise building basements. The tensioned tie rods are encased permanently in the concrete decks of the mezzanine floor of the stations.

A trenchless no-dig microtunnelling alternative to open-cut sewer installation was the TAC Project of the Year. The alternative, offered by contractor Ward and Burke Microtunnelling for a 770m section of the South Surrey Interceptor project for Metro Vancouver, was completed using a Herrenknecht microtunnelling TBM and jacking pipes designed and manufactured by Langley Concrete Group.

The Photo of the Year was awarded to the Dr Sauer & Partners and CTS JV for an impressive image of station excavation works for the Eglinton Crosstown LRT project in Toronto.

To continue the theme of recognising international collaboration, TAC is preparing to publish a book to celebrate the history of tunnelling in Canada and its 40th year of representing the industry for Canada. The book will reference Canada's rich history of all the major types of underground civil engineering infrastructure and will acknowledge the efforts of immigrants to Canada in building the national fabric of the country. ■

References

- Canada salutes top class engineering – *TunnelTalk*, November 2018
- Canada rewards national achievements – *TunnelTalk*, October 2017

From top: Lifetime Achievement: Recognition of an outstanding career brought to an end too soon; Photo of the Year: Station excavation for Toronto Eglinton Crosstown LRT

UK engineers and engineering celebrated

TunnelTalk reporting

So many projects and achievements are the legacy of the recipients of the annual BTS (British Tunnelling Society) James Clark Medal since its first award in 1981. Established in honour of the career in tunnelling of James Clark who worked for Charles Brand & Son and who was instrumental in establishing the BTS in the early 1970s, the Medal is presented to a leading UK professional to recognise a major contribution to the industry, a contemporary achievement or an innovation within the industry.

Recipients and BTS Committee guests at the annual luncheon in 2019 were welcomed at the Institution of Civil Engineers (ICE) by current BTS Chair Ivor Thomas. In his welcome address, Thomas presented a list of current UK innovations and aspirations, including the first use of a bottless trapezoidal segmental lining in the UK and a 30-30-30 initiative by a BTS workshop to strive to reduce the cost of tunnelling projects by 30%, have excavation advance faster by 30%, and both by 2030.

The BTS was founded in 1974 and is an Associate Society of the ICE. Many members of the BTS are Fellows and Members of the ICE, and many renowned tunnelling engineers and statesmen have also been President of the ICE. Membership of the ICE is not a requirement for being a member of the BTS and all those engaged in tunnelling, both in the UK and abroad, are welcome to become members and to enjoy the advantages of membership.

A second event to celebrate UK engineering achievements was held in the city of Reading, west of London, to recognise the 25th anniversary of the completion of the Thames Water London Ring Main, a system of more than 80km of deep level drinking water supply lines to households and businesses.

The gathering welcomed engineers who managed and controlled the project from its early inception, through its design, its construction and its inauguration into operation. These included Roger Remington who was awarded the BTS James Clark Medal in 1993 in recognition of his contribution and leadership of the project for Thames Water, the owner authority.

Several interesting topics were part of the discussions during the anniversary event. Some of these included the following facts:

- The IChemE Green Book form of contract, rather than the more usual ICE 5th Edition, was adopted by the project and it applied, successfully, a target cost price based procurement for the civil and tunnelling works.
- The methods of contract procurement adopted by Thames Water avoided lengthy periods of contract evaluation, with bids for many contracts being invited with a three week notice and an award three weeks later.
- Principal TBM supplier to the project, Lovat, with also Markham at the time, came to the assistance of the project in time of trouble, including on the Tooting Bec contract in South London where ground freezing was needed to rescue the TBM drive in a reach of sands and gravel within the prevailing London Clay geology. A new EPB TBM was needed from Lovat urgently to maintain programme. A further three Lovat machines were purchased to complete the second stage of the ring main project.
- At the end of the project, the full programme project was completed and delivered "two years ahead of programme and under budget".

The opportunities to honour engineers, their achievements and their projects, are rare and are so appreciated by all when they occur, not only to bring friends and colleagues together but also to ensure that the achievements of projects past are not lost or forgotten in current recollection or national industry history. ■

References

- Tideway TBMs well into excavations – *TunnelTalk*, September 2019
- Award for British inventor of slurry TBM concept – *TunnelTalk*, October 2018
- 2018 James Clark Medal recipients hosted at BTS tribute luncheon – *TunnelTalk*, October 2018
- 2017 UK honours decades of tunnelling expertise – *TunnelTalk*, October 2017
- 2016 BTS hosts James Clark Medal recipients – *TunnelTalk*, December 2016
- 2015 BTS James Clark Medal awards gathering – *TunnelTalk*, September 2015
- 2014 BTS honours James Clark Medal winners – *TunnelTalk*, November 2014
- 2013 BTS James Clark Medal awards gathering – *TunnelTalk*, November 2013
- 2011 BTS celebrates James Clark's legacy – *TunnelTalk*, September 2011

Medal recipients at the 2019 luncheon (and the year of award) from left: Alastair Biggart OBE (1991), Maurice Gooderham (2005), Alan Dyke (2006), Rodney Craig (2004), Alan Runacres (2016), Dave Court (2012), Gordon Ince (1998), Roger Remington (1993), Andy Sindall (2013), Hugh Doherty (1996), Gerard, Ged, Pakes (1997), Oliver Bevan (1992) and Terry Mellors (2011)

Beaver Award recipients

The Beavers News Release

Four renowned engineers are recipients of the 2020 Golden Beaver Awards, one of the highest honours in the field of heavy engineering construction in the USA.

Daniel Adams, President and CEO of McMillen Jacobs Associates of Seattle, Washington, was presented the Engineering Award. Adams joined Jacobs Associates in 1995, where he was sent to Melbourne, Australia, to serve as the senior tunnel design engineer for the Melbourne CityLink project. As President of the firm, Adams led the Jacobs Associates merger with McMillen in 2014.

Jack Brockway, President of Herrenknecht Tunnelling Systems USA, is recipient of the Service & Supply Award. Brockway joined The Robbins Company in 1973, where he worked his way up to become General Manager in 1991. In 1997, he joined Herrenknecht and helped to move the industry from hand mining under compressed air conditions to the pressurized face TBM systems used on soft ground tunnel projects today.

Timothy Barnard, Chairman of the Barnard Construction Company of Bozeman, Montana, received the Management Award. Starting 44 years ago with only a pickup truck and some tools, Barnard developed a successful contracting company that now has annual revenue of USD$850 million and a company culture of high safety standards.

Clayton Gilliland, Senior Vice President and Area Manager of Stacy and Witbeck, of Alameda, California received the Golden Beaver Award for Supervision. Gilliland began his 28-year construction career as a surveyor and labourer and steadily progressed through the ranks to join Stacy and Witbeck in 1999, where he has managed more than USD$2.3 billion of passenger rail construction projects in the last ten years. ■

References

- Distinguished US engineers receive top honors – *TunnelTalk*, November 2019

Top: Daniel Adams, Jack Brockway
Below: Timothy Barnard; Clayton Gilliland

Dick Robbins 1933-2019

After a career lifetime dedicated to the development of mechanized TBM tunnel excavation and the advancement of the company that his father founded in 1952, Richard James Robbins, President and CEO of The Robbins Company from 1958 to 1993, and known to everyone as Dick, died in May.

Dick was widely regarded in the international industry, building The Robbins Company into a manufacturing leader and filing 11 US patents and 56 foreign patents in the field of underground mechanical excavation. In 2009 he was the recipient of the Benjamin Franklin Medal in Engineering for his contributions.

"In 1968 when I first had the chance to work for what was then known as James S Robbins Co, I did not fully appreciate that I was getting a chance to work with the greatest innovator in the tunneling industry," said Lok Home, current owner, President and CEO of The Robbins Company. "Dick was a great mentor, as a boss and as a person. He was always pushing the limits of what could be done with TBMs. His integrity, energy, and passion improved the worldwide tunneling industry, and his creations set many of the industry standards."

"Dick gave back to his industry and to his community unselfishly," said consultant Harvey Parker, former President of the ITA and long-time friend of the Robbins family. "He was very active in industry professional associations both in the USA and internationally. I was honored to work closely with Dick during his significant involvement in the ITA, where he served on the Executive Council, was elected First Vice President, and was a leader for the ITA Working Group on Mechanized Tunnelling."

Through his career, Dick was recognized with numerous honorary degrees, memberships and directorships in organizations ranging from Virginia Mason Medical Center to the Board of Trustees at his alma mater Michigan Technological University. In 1999, the Engineering News-Record selected him as one of the top 125 people of the past 125 years as an equipment innovator who "helped shape this nation and the world".

Dick recognized the importance of sharing knowledge and experience with colleagues and fellow industry professionals and also through the pages of the industry trade magazines. In *TunnelTalk*, The Robbins Company and its TBMs feature in articles about the Severomuiski railway tunnel in Russia, started in the 1970s in Siberia, that employed a Robbins TBM for its pilot tunnel headings; the Channel Tunnel Project where Robbins TBMs were supplied to both the French and English side of the undersea connection; the Wanjiazhai Yellow River water supply tunnel in China in 2001, among the first of many Robbins TBMs to be used in China; the Blue Mountains wastewater tunnel near Sydney, Australia, on which a 3.4m diameter Robbins TBM set several advance records through sandstone; and the Lesotho Highlands Water Project in southern Africa where four Robbins TBMs helped excavate more than 80km of water transfer tunnelling beneath the highlands of Lesotho.

"Dick was always generous with his time," said Shani Wallis, Editor of *TunnelTalk*. "He, and his wife Bonnie, always had a warm welcome whenever and whenever we met." ■

Dick receives the 2009 Benjamin Franklin Medal for engineering innovation

References

- VIDEO: Face to Face with Dick Robbins – *TunnelCast*, June 2013
- Robbins celebrates 60 years of achievement – *TunnelTalk*, October 2012

Enrique Fernández González 1958-2019

There was a sense of deep loss and emptiness at many job sites and project offices around the world and among colleagues and friends at the shocking news that Enrique González of Spanish contractor Dragados lost his life after a cycling accident in March near his home close to the city of Madrid. He died at the scene of the accident.

As a professional civil engineer dedicated to the world of tunnelling, González was known on major Dragados projects and for assisting the work on job sites as the head of the tunnelling department. He was among the young generation of engineers who spearheaded the charge by Spanish contractors onto the international tunnel construction stage. González knew his industry; could build, inspire and support a team; and manage high level negotiations to win high profile projects and succeed, sometimes against all odds.

In recent times, González was celebrating with his team new high-level successes in the USA and the UK and was visiting Dragados projects in Canada the week before the tragic accident. The tour in Canada took him to the Eastern Section contract of the Eglinton Crosstown Metro project in Toronto, the Confederation Line for the Ottawa Subway, and to the metro job site beneath the city centre in Montreal.

In the USA, the newest award of contract for González and his Dragados tunnelling team was for the alternative TBM drive to create the parallel road carriageway under the Chesapeake Bay shipping channels for the Hampton Roads highway bridge/tunnel crossing. This followed the similar Thimble Shoals project where Dragados led the process to convince the client to select a TBM drive over a second immersed tube for the Chesapeake Bay crossing.

In California, González was involved in the successful proposal by Dragados to be selected for the 11.25km long x 5.5m i.d. TBM effluent conveyance tunnel in Los Angeles and its involvement, in a JV, in the construction of the first sections of the California High Speed Rail project.

Other projects in the USA included the TBM running tunnels for the East Side Access railway project in New York City and most notably the SR99 Alaskan Way double deck highway tunnel under the streets of Seattle, a project that tested the skills and abilities of González and all his colleagues within the joint venture with Tutor Perini, with contract suppliers, importantly among them Hitachi of Japan which delivered the 17.48m diameter EBPM that experienced major technical problems during its drive. It is a credit to the Dragados/Tutor Perini team that the contract survived the immediate difficulties to rescue and repair the stricken machine and bring the TBM and its drive to a successful final breakthrough in April 2018.

In the UK, the latest success is award to Dragados, in joint venture with Mace as the preferred bidder, for construction of the £1.3 billion Euston Station terminus for the High Speed Rail 2 (HS2) in London. This followed successful completion of more than 9km of twin running tunnels for the Crossrail project in London and the Bank Station upgrade for London Underground.

In Australia, involvement included the WestConnex M5 to create a significant part of the underground bypass of the Sydney centre business district and excavation and construction of the 15km of twin running tunnels for the Sydney Metro North West rail link.

Of projects in Spain, González counted among them the Calle 30 highway tunnels around Madrid in the early 2000s, using a 15m diameter Mitsubishi EPBM, and the Guadarrama high speed rail bored tunnel using a set of four TBMs, two from Herrenknecht and two from Wirth (now CREG).

Through all his project and team associations González established long lasting collaborations and friendships with fellow like-minded engineers.

González began his professional career after graduating in mining engineering from the Oviedo University in Spain with honors in 1985 and joined Arthur Andersen in its operation of auditing coal mine operations. In 1988 he joined leading Spanish contractor Dragados, and spent the first 12 years involved in projects in Spain, France, Portugal and Thailand. In 2000 he was promoted to Technical Director of the Dragados Tunnelling Division and in July 2018, he became head of the Dragados engineering company gGravity.

There is no doubt that González touched the careers and working lives of many engineers and workers and professionals in the world of tunnelling and there will be great sadness at his very untimely death. Sincere condolences are extended to his work colleagues and to his family. ■

HONOURS, AWARDS AND TRIBUTES

James Monsees

Renowned civil engineer James Monsees, of the USA, died in August 2019. Known as Jim to his colleagues, Monsees was recognised internationally as an expert in the design and construction of underground structures, and in the sciences of soil and rock mechanics.

Monsees worked for civil engineering practice Parsons Brinckerhoff, rising to Senior Vice President and Technical Director for Underground Structures. During a career of more than 50 years, he played key roles on design projects for transit, water, hydro, highways, and nuclear waste disposal, as well as in the fields of geotechnical studies, protective structures, and for on-location and laboratory-testing of soil and rock.

He served as Chief Tunnel Engineer for the first segment of the Los Angeles Metro Red Line during the 1990s, responsible for the design of all underground facilities for the heavy rail transit system. He then served as a senior advisor for technical review of the Eastside Extension of the Los Angeles Metro Gold Line, which was completed in November 2009. In 2010, he was selected by the Los Angeles County Metropolitan Transportation Authority to lead the development of seismic design criteria for all tunneling projects to be undertaken by the agency as part of its capital investment program.

Other projects on which Monsees contributed included the Central Link light rail system in Seattle; the extension of the No 7 Line subway in New York City; the West Side and East Side CSO projects in Portland, Oregon; the East Side Access railway project in New York City; and the DTSS sewerage project in Singapore and the Mexico City subway in Mexico.

Monsees earned BS and MS degrees in Civil Engineering from the University of Missouri and held a PhD in Civil Engineering (Soil and Rock Mechanics) from the University of Illinois. He was a registered professional engineer in seven states of the USA and the District of Columbia. He was elected to the US National Academy of Engineering in 1991 and was active in many industry associations including the American Society of Civil Engineers; the Underground Construction Association of the USA; the National Academy of Science, Underground Technical Research Council; the American Rock Mechanics Association; The Beavers; and The Moles.

In the early 2000s, he was part of a steering committee tasked with preparing an update of the USA Better Contracting for Underground Construction manual of 1974. Standard contract provisions had become increasingly restrictive, pushing many contractors out of the business, and were considered as possibly suppressing the development of innovative technologies. The new Recommended Contract Practices for Underground Construction was intended to provide owner agencies and their engineers with a set of best contracting practices to improve the development of contract documents and the administration of underground construction contracts to make projects more cost-effective for owners and more profitable for contractors, while contributing to the growth and advancement of the underground industry.

Monsees was also a principal author of the Technical Manual for the Design and Construction of Road Tunnels prepared by Parsons Brinckerhoff and published in 2009 by the US Federal Highway Administration. Following the September 2001 terrorist attack on the World Trade Center in Lower Manhattan, he was appointed, on behalf of a Federal Government agency, to a team of engineers and professionals charged with developing guidelines for securing underground facilities against future potential terror attacks.

In responding to a call by *TunnelTalk*, Greg Kelly President and CEO of WSP which acquired Parsons Brinckerhoff in 2014, said: “Jim brought vision, skill and deep experience to our organization and to our clients for thirty years. He was a valued colleague and friend to all and will be deeply missed.” ■

Jack Feller 1922 -2019

Expert in the heavy engineering construction industry, John Feller, better known as Jack, died aged 96 in June 2019 at his home in Orangevale, California.

Jack was well known within the tunneling industry of North America as a President of the Beavers, as Chairman of the annual Beaverdilly, and as one of the four founding officers in 1977 of the Beavers Charitable Trust.

The oldest of three brothers, Jack was an enterprising, engaging, and adventurous person. From his first job selling magazines aged 7, he worked continuously until November 2018, when he finally retired for the last time. After serving in the United States Army Air Corps during WWII, he returned to school to pursue a degree in Civil Engineering at the University of South Dakota.

After completing his studies, he pursued his career in heavy civil construction, working his way up through the levels of responsibility from project manager, to Vice-President, President, CEO, and Chairman of the Board. He ended his career as an Arbitrator.

He was accomplished at all his endeavors and challenged others to be the best they could be. With a great sense of humor and unwavering Christian faith, Jack had a very generous heart and was moved to help as many as he could. ■

Vladimir Ratkowsky 1930 -2019

After a long career as advisor and technical consultant for project owners, contractors and government bodies, and a long association with the ITA, Vladimir Ratkowsky of Slovakia, died in June 2019 after a long standing illness.

Vladimir, known as Vlado to friends and colleagues, was closely connected with the ITA and contributed significantly to membership of Czechoslovakia, as it was then, as a Member Nation in the ITA since early establishment of the international Association in 1974. This effort and dedication laid the foundation stones for the membership of the later Czech Republic and Slovakia in the ITA together with encouragement to other Eastern European nations to become Member Nations of the Association.

As the representative to the ITA, he was a lecturing member and presenter at the annual ITA congresses and was part of the organising committee that hosted the ITA Congress and General Assembly of Member Nations in Prague in 1986 and again to Prague in the Czech Republic in 2007.

For a time, he also worked in the UK in the Tunnels Division of the then Transport and Road Research Laboratory.

Vlado graduated from the faculty of Civil Engineering at the Slovakian Technical University in Bratislava, majoring in traffic structures. In Slovakia, he was one of the leading scientists and consultants in the field of underground construction and specialized in both municipal road construction and long-distance rail and road connections in his country.

After qualifying as an Assistant Professor in 1979 he used his excellent knowledge of tunnel construction, both mined and cut-and-cover techniques, for scientific research, consulting activities, and the training of young engineers.

He was best known for his work in the preparation phase of the Bratislava Metro and the construction of various shield-driven public utility lines and road tunnels. He strongly influenced development and progress in the field of underground construction in Slovakia.

“Vladimir will be missed by all associated with the Slovakia Tunnelling Association, as well as the tunnelling public, as a long-time educator who has trained several generations of tunnelling experts involved in the current construction of tunnels in Slovakia and abroad,” said Miloslav Frankovsky, current Chairman of the STA. “He was a fine person and a kind friend to all of us.” ■

David R Yankovich 1953 - 2019

After a career in civil engineering, with particular expertise in the design of complex tunneling projects in the USA, David Yankovich died peacefully at his home in Las Vegas, Nevada, in January 2019, aged 66.

Yankovich was born in Albany, New York, and obtained a BS in Civil Engineering at Union College, Schenectady, New York, in 1981 and a MS in Civil Engineering from Worcester Polytechnic Institute, Massachusetts, in 2000. He worked his way through his schooling at a foundry and as a practicing engineer.

He was a member of the American Society of Civil Engineers and was a licensed professional engineer in the States of California and Nevada and of structural engineering in Arizona and Massachusetts. He worked for Sverdrup and Black & Veatch in project engineering and project management before joining Parsons in 2008. While with Parsons he worked as a project manager and as Vice President overseeing water and wastewater tunnel projects.

As a civil engineer in the United States and on projects overseas, his expertise and experience encompassed planning, design and construction services for water and wastewater and transportation projects.

Some of his major projects throughout his career included:

- the Big Dig underground highway project in Boston;
- the Clean Water Conveyance and Operations Program in Las Vegas;
- Phase 1 and 2 of the Central Outfall Sewer Rehabilitation project for the City of Los Angeles; and
- the Deep Tunnel Storm Water System in Dubai.

Yankovich dedicated much of his last 10 years to the design of the new effluent outfall tunnel for the Sanitation Districts of the Los Angeles County Clearwater Project. At a groundbreaking ceremony in May 2019, he was remembered for his commitment to the project. ■

James Barbera 1940-2019

Manufacturer of trenchless installation equipment, and an influential figure in the trenchless industry, James (Jim) Barbera died in July 2019.

A graduate of Timken Vocational High School, Barbera went on to serve in the US Army before working for the Canton City Police Department until 1974. He worked then for his brother, Leo Barbera, at American Augers where he oversaw the sales department and had direct oversight of several initiatives, including the reconditioning of a 19ft Robbins TBM. He was an active organiser in the auger boring schools that were held in Arizona.

In 1989, Barbera founded Barbco. Based in Twinsburg, Ohio, the company manufactured directional drills and pilot tube machines. The company expanded considerably in both facility size and product line, moving to East Canton, Ohio, in 2003, where it has been run by three of his sons for the past five years.

Jim and Leo Barbera, centre left and right respectively, receiving their Lifetime Achievement Awards with Professor Tom Iseley (left) and friends

Both Barbera brothers were honoured by the Trenchless Technology Center (TTC) at Louisiana Tech University with Lifetime Achievement Awards for their contributions to the trenchless industry. Additionally, a new training and educational facility, the Barbera Education, Research and Training (BERT) Facility, is being erected in the family’s honour at Louisiana Tech University.

“From the first time I met Jim over 30 years ago, I was impressed with his commitment to workforce development,” said Tom Iseley, Professor of Civil Engineering and Construction Engineering Technology and Associate Director of TTC at Louisiana Tech University. “He clearly understood that organisations could have the best equipment in the world but without properly trained and motivated crews, successful projects are at risk. He was overwhelmed to have the training facility named after him.” ■

Giovanni Barla 1940-2019

Influential rock mechanics researcher and former Professor of Rock Mechanics at the Politecnico di Torino in Italy, Giovanni Barla died in November 2019. As Head of the Department of Structural and Geotechnical Engineering at the Politecnico di Torino from 2003 to 2011, Barla was also Editor in Chief of the journal Rock Mechanics and Rock Engineering. He was a past President of the Italian Geotechnical Association (AGI) and Vice President for Europe of the International Society for Rock Mechanics (ISRM).

Barla received many recognitions through his long and distinguished career including being elected as a Fellow of the ISRM in 2012; awarded for outstanding contributions from the IACMAG in 2014; and granted Emeritus Membership of the AGI in 2015. He was a member of the Torino Academy of Science and a renowned international consultant.

Graduating in mining engineering from the Politecnico di Torino in 1965, Barla specialised in rock mechanics for his post-graduate work and obtained a Masters Degree from Columbia University, New York. He was awarded the Doctor of Engineering Science Degree from Columbia University for a thesis on stress analysis of underground excavations.

His research interests spanned several specific topics in the fields of rock mechanics, tunnel engineering, rock slope and dam engineering, and numerical methods in geomechanics. He acted as designer, geotechnical consultant, or was responsible of the numerical studies for a wide range of rock, geotechnical, and mining engineering projects.

His reputation will live on in his many authored and co-authored papers and text book publications in his specialist fields. ■

Fred Benjamin Estep 1938-2019

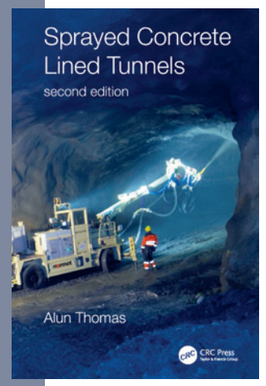
Well known to the civil tunneling and hydropower industries in the USA, Fred Estep was a professional civil engineer for 45 years. He spent the last 10 years of his working life between 2000 and 2010 with civil engineering practice Parsons as a construction manager on the San Vicente water tunnel in San Diego, the Chattahoochee sewer tunnel in Atlanta, and the Los Angeles Metro.

Before that he spent 35 years at Tudor Engineering Company, which in 1990 merged with Kaiser Engineers. While there, he worked on BART and MARTA metro systems in San Francisco and Atlanta respectively; the Exchequer and Austrian Dams in California; the Rollins, Sly Creek, Monticello, Jones Fork, and North Fork hydroelectric projects in the USA; and the South Bay tunnel outfall in San Diego.

Estep gained a BSc in Agriculture from UC Davis and a BSc in Civil Engineering and another in Industrial Engineering from the University of Washington. He also contributed to the fields of rapid transit, roads and highways, bridges, dams and hydroelectric powerhouse designs. ■

Sprayed Concrete Lined Tunnels - 2nd Edition

- Author: Alun Thomas
- ISBN: 9780367209759
- Pages: 274pp
- Published: September 2019



In this second edition of the book, beyond a general update to reflect new developments, the sections on permanent sprayed concrete, the innovative technology of spray applied waterproofing membranes, fibre reinforcement (both steel and macro synthetic), and composite lining design have been expanded. Sustainability and environmental impact is also addressed in a new section.

Other chapters of the book address:

- What is an SCL Tunnel?
- Sprayed Concrete
- Construction Methods
- Design Approaches
- Modelling Sprayed Concrete
- Detailed Design
- Construction Management

Sprayed concrete lined (SCL) tunnels are growing rapidly in popularity due to their versatility. The design and construction of both hard rock and soft ground tunnels has been revolutionised by the advent of the SCL method. The use of permanent sprayed concrete linings has now unlocked the true potential of the method to minimise construction costs and times. Yet the complex early age behaviour of sprayed concrete makes the design difficult and requires a robust management system during construction. Consequently, the great advantages of the method must be balanced against the risks, as a few high-profile tunnel collapses have illustrated.

Practising engineers on site, in the design office, or in client organisations will find Sprayed Concrete Lined Tunnels an excellent introduction to the topic. It covers all aspects of SCL tunnelling – from the constituents of sprayed concrete to detailed design and management during construction. Although there is a close interdependence between all the facets of sprayed concrete, few engineers have the right breadth of experience and expertise to cover all of them. This needs urgently to be transferred to the wider engineering community as SCL tunnels play an increasingly important role in the delivery of the underground infrastructure that modern urban life demands.

Printed hardback (£110) and ebook (£90) versions are available to order from CRC Press. ■

Ground Characterization and Structural Analyses for Tunnel Design

- Authors: Benjamín Celada, Z.T. Bieniawski
- ISBN: 9780815386629 - CAT# K345074
- Pages: 454pp
- Published: August 2019

This practical and design-oriented book focuses on ground characterisation and structural calculation, as part of the active structural design methodology. With a focus on rock tunnelling, it offers a comprehensive, rather than a topic-based perspective, deriving sound tunnel design criteria and methods from basic principles. Ground characterisation includes excavations, site investigation, and in-situ stress determination, culminating in geotechnical classifications. The book then deals with various construction methods and their appropriate calculations, which range from constitutive models for the stress-strain behaviour of an excavation and tunnel support elements to a full stress–strain analysis methodology.

The heavily practical approach of the book draws on 20 years of tunnelling experience in Spain and South America. It will help any young or established professional who wants to develop a career in the underground field across both civil engineering and geology. As it incorporates the very fundamentals of tunnelling design, it can be used as a support for tunnelling courses or as a textbook for Masters and PhD courses.

Benjamín Celada was Chief Tunnel Engineer at Hunosa and Potasas de Navarra S.A. before founding Geocontrol S.A. He has also worked for twenty years as Professor of Underground Works at the Polytechnic Mining University in Madrid, Spain.

Z. T. Bieniawski directed the Rock Mechanics Department of the Council for Scientific and Industrial Research in Pretoria, then taught at the Pennsylvania State University for 20 years.

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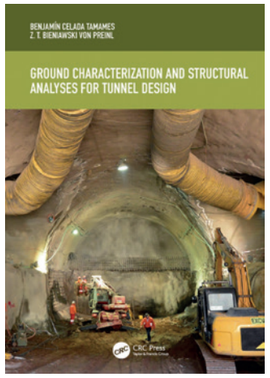

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