

INTERNATIONAL EDITION

March 2015

Tunnels

AND TUNNELLING

KARGI HEPP

*A worker pauses
while a side mounted
conveyor removes
mixed ground from the
Kargi Hydroelectric
Power Plant*

+

Latin America

Conveyors

Fire

Client:
› Southern Nevada Water Authority (SNWA)

Contractors:
› Vegas Tunnel Constructors
› Salini Impregilo S.p.A.
› S.A. Healy Co.

15 Bar

Tunnelling under **highest water pressure** to secure the water supply for the dry-running city of Las Vegas. Herrenknecht and Vegas Tunnel Constructors jointly mastered even unpredictable conditions with a powerful TBM.

Worldwide

Unique project at Lake Mead: 140m depth, 4,4km tunnel length, 3 years' determined work.

Record

Outstanding success for a Herrenknecht Multi-mode TBM: for the first time a tunnel boring machine **tackled and withstood** 15 bar water pressure.

Pioneering Underground Technologies

› www.herrenknecht.com/lakemead



TUNNEL SCIENCE

THERE ARE rumblings in the scientific community. Today's cutting-edge physics is largely impossible without the use of underground space, and there have already been a number of interesting developments this year for the industry to take pride in.

Last month I highlighted the work of the ITA and the tunnelling community to help people living in cities and natural disaster-prone areas live better, safer lives. But tunnelling also helps advance human knowledge.

In January, the India Based Neutrino Observatory (INO) (featured T&T January 2011, p.27) finally got the go ahead after four years of environmental and funding delays. Neutrinos are extremely subtle, non-reactive particles that pass through virtually everything. As a result, detectors are in deep mines or tunnelled deep into mountains, which filters out all the other 'noisier' particles. The USD 240M INO will be built with 1.3km of rock cover inside a mountain in a mountain in Tamil Nadu, India. It will be accessible only through a 2km approach tunnel that opens to three caverns, the largest of which will be 132m long by 26m wide by 30m high.

The Tohoku region of Japan has likely had enough of atom smashing technology, following the aftermath of the 2011 Earthquake and Tsunami that resulted in the meltdown of one of the Fukushima Daiichi Nuclear Plant's reactors. But particle accelerators are much safer, and the region is a leading candidate to house construction of the International Linear Collider (ILC). This 40km-long facility could total anywhere between USD 10-25bn, according to vague US Department of Energy estimates. And the solid granite of the proposed Japanese sites would keep it well protected. The ILC would fire electrons and positrons (positively charged electrons, a form of antimatter) into each other to simulate conditions shortly after the Big Bang.

Ready to break back into public consciousness, the Large Hadron Collider (LHC) of Switzerland is continuing to prove its usefulness. This behemoth is due to come back online this month with some hefty two-year upgrades to its power. Never

Alex Conacher
Editor



mind the electron, this facility launches protons many thousands of times larger into one another. It earned a Nobel Prize in 2012 for filling in a blank in the Standard Model of particle physics with the discovery of the Higgs boson, first hypothesised in the 1960's.

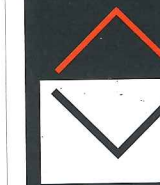
Physicists aren't happy. What has been so far observed fails to explain some of the bigger problems of the field. So this time, when they turn the accelerator back on, they will attempt to challenge everything we have seen so far. Anyone interested should read up on the theory of Supersymmetry (SUSY).

And finally in the US, the 4km-long Relativistic Heavy Ion Collider (RHIC), which is second in power only to the LHC, is coming out of hibernation since it's last great feat in 2010; when it showed that at approximately four trillion degrees Celsius, normal matter breaks down into quark-gluon plasma. So while the LHC reaches to understand the new and exotic, the RHIC is using its still considerable power to peer more closely at the features of the types of matter we already know.

All this activity, and we're not even three months into the year

editor@tunnelsonline.info

What do you think? Send your views to the editor and join the debate



This month...

20 YEARS AGO

As one Los Angeles Metro Red Line tunnelling contract starts, another stops. Still, it's all go for the MTA. Following a further 1.5in of subsidence beneath Hollywood Boulevard, the MTA has ordered a temporary halt to excavation as a precautionary measure.
Tunnels and Tunnelling, March 1995, p.9

30 YEARS AGO

British Rail would benefit if it was able to build a fast new railway link to Heathrow Airport. This conclusion follows the success of the express train service introduced last May between London Victoria Station and Gatwick Airport. The line to Heathrow would be in a tunnel some 6 miles long, including 3 miles passing beneath the main terminal. Possible cost is estimated at GBP 100M.
Tunnels and Tunnelling, March 1985, p.7

40 YEARS AGO

The Channel Tunnel project, recently dealt a death-blow by the British Government, refuses to stay down. The EEC Commission at Strasbourg has urged the British and French governments to reconsider their decision. Will the Europeans take the initiative or is it a storm in a teacup. Certainly there is little excitement among the contractors yet.
Tunnels and Tunnelling, March 1975, p.11

Cover

A continuous conveyor mucks the Kargi hydropower project. See conveyors feature, p.27.



Next issue

In the next issue of Tunnels and Tunnelling we are featuring two site reports from Central Europe: the Koralm and Brenner base tunnels. Readers interested in these projects should also read our 'Lessons learned from base tunnels' special feature this October.

ALWAYS ADVANCING

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DOUBLE SHIELD TBM

TERRATEC celebrates its 25th Anniversary by delivering a new Hard Rock Double Shield Tunnel Boring Machine for Xe-Pian Xe-Namnoy Hydroelectric Project in Laos.

The Tunnelling Contractor, SELI Overseas S.p.A. preferred TERRATEC to design and manufacture the TBM. With this milestone, TERRATEC consolidates its sales expansion of Hard Rock TBMs into the global market.



TUNNELLING SOLUTIONS | HYDROPOWER



Left: Aerial view of Access Shaft Three at the Sistema de Potabilizacion Area Norte project in Buenos Aires, Argentina. See page 40

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A look at the advances made in fire safety and evacuation protocols in metro tunnel projects. From ventilation to test scenarios

What do you think? Send your views to the editor and join the debate
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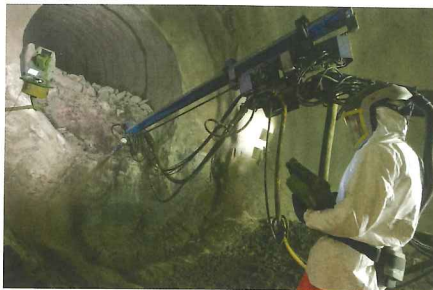
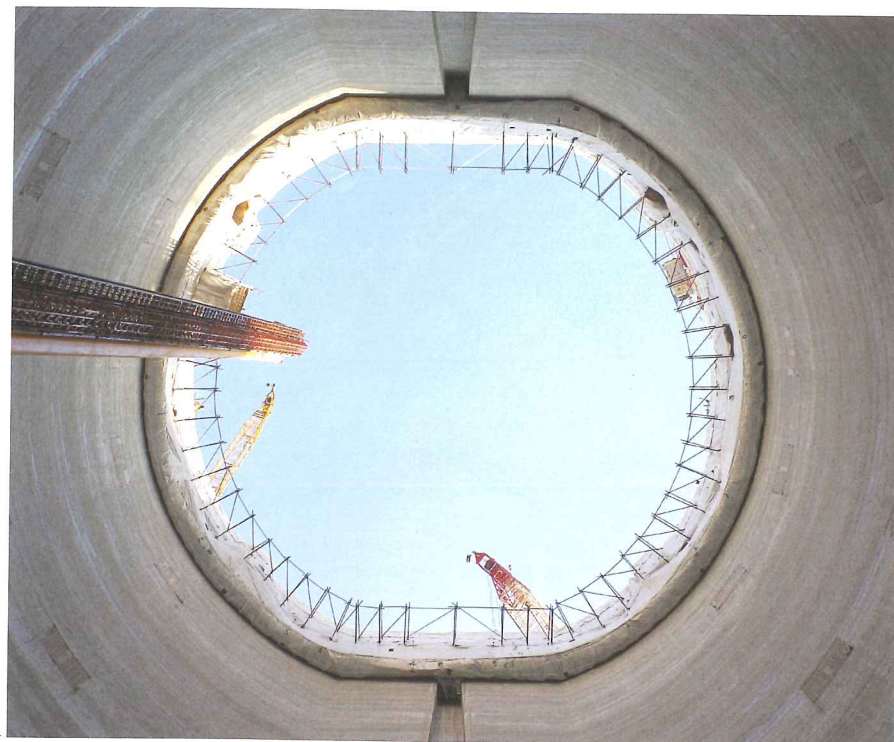
CLAUDIO CABRAL DIAS
Claudio currently works as a tunnel design engineer for Halcrow CH2M Hill in the UK.

FERNANDO HIRATA
Fernando works as a geotechnical engineer for the Sao Paulo Metropolitan Company.

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Flavio works as a technical director for Infra7 Consulting and Engineering in Brazil.

SALLY SPENCER
Sally joins Tunnels and Tunnelling as a contributing editor. You can read her debut article on page 33.

KEREN FALLWELL
Keren joins Tunnels and Tunnelling as a contributing editor. You can read her debut article on page 27.



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CONSTRUCTING A SUSTAINABLE FUTURE

At VINCI Construction Grands Projets, we engineer solutions that are not only financially competitive, but also work in a way that is sustainable for the planet.

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To learn more please visit www.vinci-construction-projects.com/british-isles



Discover more...



GRANDS PROJETS

Major Follo Line contract awarded

NORWAY — The Norwegian National Rail Administration has awarded the main tunnel contract for the Follo Line project. The TBM bore will be executed by a joint venture of Acciona Infraestructuras and Ghella. This is the largest railway contract to date in Norway.

The contract has a value of NOK 8.7bn (USD 1.08bn) and is scheduled to be signed before Easter and the work will commence immediately thereafter. The award value is within the project budget. The JV won based on an overall assessment of price and technical feasibility and performance.

The contract covers both conventional drilling and TBM work, in addition to railway system installations and comprises construction work to be performed without proximity to railway operations. This is the second of four large EPC contracts for the Follo Line Project, currently the largest infrastructure project in Norway.

This contract includes the blasting of large assembly halls located approximately

1 km inside the mountain. Access tunnels to this area are currently under construction under a separate preparatory contract. In the assembly halls, the four tunnel boring machines will be assembled from prefabricated parts prior to operation. The tunnel boring machines will have a diameter of less than ten meters. Two separate tunnels of 19 kilometers each, will be excavated by TBM between Oslo and the new Ski station. Two machines will drill north towards Oslo and two machines will drill southward toward Ski.

The northern part of the tunnel will be operated partly by conventional methods and partly by drill & split. This work is part of another contract.

The JV will also perform all the railway installations, with the exception of the signal system.

All mechanical and electrical equipment in the tunnel will be installed in approximately half of the 44 cross connections to be built between the two tunnels.

The Follo Line will comprise 20km of twin tube tunnel excavated by TBMs just under 10m in diameter.

RULING ON CROSSRAIL TRAGEDY

GREAT BRITAIN — The inquest into the death of a Crossrail worker has ended with the jury ruling that the death was accidental with contributory factors. No one will face prosecution.

Rene Tkacik, who was "hugely experienced" working with sprayed concrete, was crushed to death by "just under a tonne" of poured concrete on 7 March 2014.

The jury ruled that poor English skills led to Tkacik being unable to understand all briefings. The exclusion zone definition was also unclear as it sometimes changed. The BBC reported that Tkacik was found within such a zone, where wet concrete was being poured. And that it was not clearly marked at the time of his death. Since the incident, safety ropes and chains have reportedly been brought into use.

Tkacik was working in the tunnel some 24m below Fisher Street, London; a depth that meant emergency personnel took six minutes to reach him from the surface.

Crossrail released the following statement: "Safety has always been, and continues to be, the number one value for Crossrail and is critical to the delivery of the project. Crossrail has a good safety record and sets the most stringent contractor safety requirements in the industry. There is nothing so important on Crossrail that it cannot be done safely."

Tkacik, a 44-year-old Slovakian construction worker had travelled to London for work. He had been sending money to his family in Slovakia.



Work underway at the Fisher Street Crossrail site

News briefs

SCOTLAND

The Scottish Labour party leader, Jim Murphy, announced at the Core Cities UK Devolution Summit last month that if Labour win the 2016 elections, they will implement a multi-million pound 'Crossrail-style' project, describing it as the "missing link" in the Scottish railway system. Murphy stated that the new Holyrood borrowing powers would be used to fund the project which would link the north and east to those in the south and west of Scotland.

CANADA

A man who dug a tunnel under Toronto and caused a media frenzy last month said the 'man cave' was merely his dream hang out spot. Authorities initially investigated the possibility of a terrorist connection to the mysterious tunnel. But Elton McDonald, 22, says the tunnel was simply a private getaway. "It was a secret for sure, but it was not built for nefarious reasons," McDonald told The Toronto Sun. "It was a place that no one knew about." Mr McDonald constructed the 10m-long, 2m-high tunnel, near his family's home two years ago.

Sponsored places up for grabs on BTS Tunnel Design and Construction course

GREAT BRITAIN — This year there are five sponsored student places available for the annual BTS Tunnel Design and Construction course held at Warwick University from 29th June to 3rd July. This sponsorship includes the course fee and accommodation for the week.

This course aims to provide a comprehensive introduction to all aspects of tunnelling. The course

speakers are industry experts, and the course is recognised within the industry as providing the highest standard of technical content, with the course material being presented in a format designed to engage and inform attendees.

The deadline for submissions in Friday 24th April. For more information, please visit: <http://tinyurl.com/ogsy2no>



The first bore of the Waterview Connection project

ALICE TAKES A BREATH

NEW ZEALAND — The backup train of the Waterview Connection TBM was in the process of being turned to join up with the cutterhead and shield already working on its second bore path as Tunnels and Tunnelling went to press.

Construction work paused on 20 February after the TBM, with support from a temporary gantry setup, had excavated the required 270m of the second tunnel.

New Zealand Transport Agency highway manager Brett Gliddon said: "There is now enough room bring all the necessary gear into the tunnel so that we can complete the job."

The temporary gantry has to be removed. And the two remaining gantries - which contain all services and backup equipment for TBM operation - have to be pulled from the first tunnel, turned 180 degrees inside the Northern Approach Trench (NAT), and then reconnected to the cutter head. The culvert-laying gantry being used to build the services culvert on the floor of the main tunnels behind Alice also has to be removed from the first tunnel, turned, and installed in the second.

As with the first stage of the turnaround, there are only centimetres to spare in the trench so it will be a very delicate and careful operation. "Turning a TBM of this size has

only been done a couple of times before, and we expect there will be a world-wide audience watching the turnaround of the remaining gantries," Gliddon said.

Gliddon added: "The turnaround is expected to take 10 weeks and Alice will then be ready for her main drive south towards Owairaka to complete the second - northbound - motorway tunnel. Breakthrough at Owairaka is expected next spring."

The Waterview Connection project is planned to open to traffic in early 2017. It is being delivered by the Well-Connected Alliance which includes the Transport Agency, Fletcher Construction, McConnell Dowell, Parsons Brinckerhoff, Beca Infrastructure, Tonkin & Taylor and Japanese construction company Obayashi Corporation. Sub-alliance partners are Auckland-based Wilson Tunnelling and Spanish tunnel controls specialists SICE.

Both bores are 2.4km-long and are being excavated by the same 14.4m-diameter Herrenknecht EPBM. For the most part the tunnel route passes through sandstone and siltstone that varies in strength from 1MPa to 5MPa.

This is also featured as our Big Picture story, pp.26-27

UCATT publishes guide to damage 'blacklisters'

GREAT BRITAIN — Construction union UCATT has launched a new guide that details how companies accused of being involved in blacklisting can be barred from public procurement projects.

A UCATT spokesman said, "The pocket sized guide Blacklisting and Public Procurement is designed for UCATT members to lobby public sector bodies such as local authorities and NHS Trusts to persuade them to adopt policies that will prevent companies involved in blacklisting from tendering for contracts.

"The guide also provides advice on how members can lobby and influence public authorities to cancel contracts that have been previously awarded to companies involved in blacklisting."

Crossrail begins archaeological dig at Bedlam site

GREAT BRITAIN — Archaeologists have started excavating around 3,000 skeletons from the Bedlam burial ground at Liverpool Street in the City of London.

The excavation will allow construction of the eastern entrance of the new Liverpool Street Crossrail station.

A team of 60 archaeologists will work in shifts, six days a week to remove skeletons and carefully record evidence for what may prove to be, in archaeology terms, London's most valuable 16th and 17th-century cemetery site. The excavation is being undertaken by MOLA (Museum of London Archaeology) on behalf of Crossrail.

The Bedlam burial ground was in use from 1569 to at least 1738, spanning the start of the British Empire, civil wars, the Restoration, Shakespeare's plays, the Great Fire of London and numerous plague outbreaks.

The year 2015 marks the 350th anniversary of London's last Great Plague in 1665 and archaeologists hope that tests on excavated plague victims will help understand the evolution of the plague bacteria strain.

Jay Carver, Crossrail's lead archaeologist said: "This excavation presents a unique opportunity to understand the lives and deaths of 16th and 17th century Londoners. The Bedlam burial ground spans a fascinating phase of London's history, including the transition from the Tudor-period City into cosmopolitan early-modern London.

"This is probably the first time a sample of this size from this time period has been available for archaeologists to study in London. The Bedlam burial ground was used by a hugely diverse population from right across the social spectrum

and from different areas of the City."

Nick Elsdon, Project Manager from MOLA said: "Construction for Crossrail is providing rare and exciting opportunities for archaeologists to excavate and study areas of London that would ordinarily be inaccessible, such as under established road-systems. There are up to six metres of archaeology on site, in what is one of the oldest areas of the city, so we stand to learn a great deal."

The research also aims to shed light on migration patterns, diet, lifestyle and demography of those living in London at the time. Excavated skeletons will be taken to MOLA for testing by osteologists (specialists in bone analysis) before being reburied in a consecrated burial ground.

The skeletons will be excavated over the next four weeks, after which archaeologists will dig through medieval marsh deposits and Roman remains. A Roman road runs under the site, which has already yielded several interesting Roman artefacts such as horseshoes and cremation urns.

Archaeologists are expected to finish onsite in September, after which construction will proceed on the new eastern ticket hall by the contractor Laing O'Rourke.

Historical tunnel mapped by laser scanners in Utah

USA — Zion National Park in Southern Utah plans to light up its historic Zion-Mount Carmel Highway Tunnel with lasers.

This will be used to create a highly detailed, three-dimensional model of the 85-year-old tunnel, which will be closed to traffic for the mapping.

The 3D laser scanners should help Zion's cultural resources staff learn

TUNNEL CONSTRUCTION STARTS ON HONOLULU WASTEWATER PROJECT

USA — Honolulu Mayor Kirk Caldwell announced the start of tunnel construction for the City and County of Honolulu's Kaneohe-Kailua Gravity Sewer Project, on February 13.

The three-mile (4.8km) line running mostly under Oneawa Hills is a gravity sewer tunnel that will convey wastewater flows and store wastewater to prevent overflows and spills. Tunnelling will start at the Kailua treatment plant, approximately 62ft (18.9m) below ground, and the tunnel will be approximately 35ft (10.67m) below ground at the Kaneohe Pretreatment Facility.

The contract for the Kaneohe-Kailua gravity sewer tunnel project was awarded to the joint venture group of Southland Contracting, Inc. and Mole Construction, Inc. (Southland Mole JV) and the construction management contract was awarded to local construction management firm Bowers + Kubota.

Wilson Okamoto Corporation is the project's civil engineer, with McMillen Jacobs Associates as the tunnel engineer and YK Engineers, LLC the project's geotechnical engineer.

Southland Mole JV is using a 13ft (4m) diameter Robbins TBM. According to Robbins, the TBM is refurbished with some components from Southland's recently completed Jollyville Tunnel in Texas.

In order to move the tunnel away from populated areas, designers introduced an isolated curve in the tunnel alignment of 500ft (152m) radius, requiring the TBM to be specially designed. Operators will also follow a procedure of 1/2 strokes while navigating the curve.

"This is a big win for Oahu," said Caldwell, "Consider the benefits to our environment, to job stimulation and to neighborhoods on the Windward side that will have a safe, out-of-sight wastewater system with incredible storage capacity."

Aikahi Elementary School's robotics team named the TBM "Pohakulani" which means "Rock Girl" in Hawaiian.

more about the tunnel's exact dimensions and the construction materials used to build it — information impossible to get without closing off the area for long periods.

Construction of the 1.1 mile Zion-Mount Carmel Tunnel began in the late 1920s.

The completed passage through a sandstone cliff hundreds of feet above the canyon floor was dedicated on 4 July 1930, as part of an effort to link national parks in the region.

The 3D scanning will also help park officials check the structure's condition, especially after accidents or other incidents.

Last year a tractor-trailer got stuck at the western end of the tunnel. And a few years ago, there was a car fire inside. The tunnel is off-limits to tractor-trailers and other large commercial vehicles, bicycles and pedestrians.

Private vehicles wider than 7ft 10in (2.4m) or taller than 11ft 4in (3.5m) are allowed with a special permit.

BERTHA BREAKS INTO REPAIR PIT

USA — Seattle Tunnel Partners (STP) advanced the TBM mining the Alaskan Way Viaduct replacement tunnel in late February into the access pit where it will disassemble the machine to perform repair work.

The 17.5m-diameter TBM, with a damaged seal system, mined through 20ft (6m) of unreinforced concrete to reach the interior of the pit.

Crews completed excavation on the 80ft (24.4m)-wide circular shaft, 120ft (37m) deep on January 30, and then built a concrete cradle on the bottom to support the TBM upon reception, before the TBM began mining on February 17.

The TBM, Bertha, is being used by Seattle Tunnel Partners - a joint venture of Dragados USA and Tutor Perini - to build a 3.2km tunnel to replace the SR 99 Alaskan Way Viaduct in Seattle. In December 2013 Bertha encountered an obstruction.

Approximately 20,000cu.yd (15,300cu.m) of soil has been removed from the pit over the course of excavation. Because a number of other important construction activities are competing for space near the pit, there will be many



Excavation was halted over a year ago

days when excavation doesn't occur. Contaminated soil was hauled by truck or barge to a disposal facility; STP has stored non-contaminated soil and will use it to fill in the pit after tunneling resumes.

Auckland Mayor calls for early start to CRL

NEW ZEALAND — Auckland mayor Len Brown has put pressure on the central government to commit to an early start for the City Rail Link, as new data shows a record 13 million train trips in the past 12 months.

Brown said Auckland's rail network was on track to reach 20 million passengers annually by 2018, which would meet the government threshold for bringing forward construction of the NZD 2.4bn rail tunnel.

More than 13 million journeys were made on Auckland trains in the year to March, up 19 per cent compared to this time last year. The figures included a 176 per cent jump in people taking the train to Manukau and a 50 per cent rise on Eastern Line stations.

Brown said the figures showed the need to start building the CRL by next year. "Aucklanders are behind (the CRL), the business and investment community are behind this, we just need to get on and get it done."

If the current rate of growth continued, patronage would balloon to 15 million trips annually by the end of the year. Existing

infrastructure will be at capacity this year.

Brown attributed the rise in patronage to the rollout of electric trains and commuters wanting alternatives to congested traffic. "If we can build it, they will get out of their cars and use it."

Grand Istanbul Tunnel unveiled

TURKEY — Turkey has announced plans for a new Bosphorus crossing. The USD 3.5bn megaproject will be a three-level tunnel connecting Europe and Asia.

Two levels will house roads, with the third a metro rail route. The section with both road and metro in spans 16.8m in diameter and will run for 6.5km below the sea. The sea is approximately 65m deep in this part of the Bosphorus.

According to Turkish Prime Minister Ahmet Davutoglu the project, which last month he named "Grand Istanbul Tunnel" would be the first of its kind in the world.

Tendering should be complete in time for Turkey's general election on 7 June. The aim is to open the tunnel in 2020. "Istanbul is a city which shapes history, it deserves the best, including mega-projects" Davutoglu

said, while presenting the new project in an event organized by the Ministry of Transportation. "The three-level mega project will be the signal flare of the Turkish Republic, the fourth global state in Istanbul after three empires,"

Thames Tideway preferred bidders announced

GREAT BRITAIN — Thames Tideway has revealed the contracting joint ventures that will each build a portion of the mega tunnel. The project, which is split into geographical sections of west, central, and east, will be the biggest project ever undertaken by the UK water industry.

The contractors which have been chosen as the preferred main works tenderers are: BMB JV (Joint Venture of BAM Nuttall Ltd, Morgan Sindall Plc and Balfour Beatty Group Limited) for the West contract, FLO JV (Joint Venture of Ferrovial Agroman UK Ltd, Laing O'Rourke Construction) for the Central contract and CVB JV (Joint Venture of Costain Vinci Construction Grands Projects Bachy Soletanche) for the East contract.

The project, which will be the biggest infrastructure project ever undertaken by the UK water industry, will make London's sewerage network fit for the 22nd century and will help prevent the millions of tonnes of sewage pollution that currently discharge into the tidal River Thames every year.

The contracts are expected to be awarded in the summer, when the investors who will be chosen to finance and deliver the project as the Infrastructure Provider, are announced.

Andy Mitchell, Chief Executive at Thames Tideway Tunnel, said: "This is not just an engineering project, this is about reconnecting London with its river by cleaning it up and making it something that is integral to our city, for the growing population, thriving businesses and to increase leisure uses."

"This is a unique opportunity to be involved in improving London's environment and economy and we're very excited for what the future holds."

The contract values for the lots are GBP 300-500M (USD 450-750M) for the western section; GBP 600-950M for the central section; and GBP 500-800M for the eastern section.

ITAWTC 2015

41st General Assembly and Congress of International Tunnelling Association ITA-AITES



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TUNNELLING COMPLETE ON HARBOR SIPHONS PROJECT

USA — The TBM mining some 35m below New York Bay completed on January 28, on the 2.9km-long tunnel for the New York City Harbor Siphons Project.

The tunnel, between Brooklyn and Staten Island, was designed to replace two existing shallow water lines below the bay to make way for a larger project -- dredging of the Anchorage Channel, which will allow for mega ships carrying large cargo loads to pass through.

Tully/OHL USA JV procured a 3.8m diameter EPB TBM from Caterpillar in 2012, which was designed to drive through highly variable clays, sands, weathered rock and boulders. It was launched from the 35m deep Staten Island shaft, boring towards the 40m deep Brooklyn shaft, in August 2012.

In October 2012 Superstorm Sandy hit the East Coast with winds up to 145 kph. Extreme flooding at the waterfront jobsite in Staten Island overtopped protective concrete barriers that had been designed 3ft (1m) above the 100-year flood level. Seawater rushed into the

tunnel and the nearly 113m-long machine was entirely submerged only 460m into its drive.

"Obviously this was our biggest challenge," said Luis Alonso, tunnel manager for OHL. "After that, not many people thought we would be able to finish this tunnel."

The TBM was severely corroded by saltwater and sat idle until July 2013. During that time, CAT announced its impending closure of its TBM business, and the contractor looked to other manufacturers.

"OHL was always determined to finish this project," Alonso said. "After studying other options, we decided to proceed with the full refurbishment of the TBM with the help of The Robbins Company."

The rebuild took about four months, much of it done in the tunnel under water pressure, and crews were able to return to mining on April 14, 2014.

Machine performance steadily increased, eventually reaching rates as high as 30.48m per day and as much as 25 rings in 24 hours in August 2014.

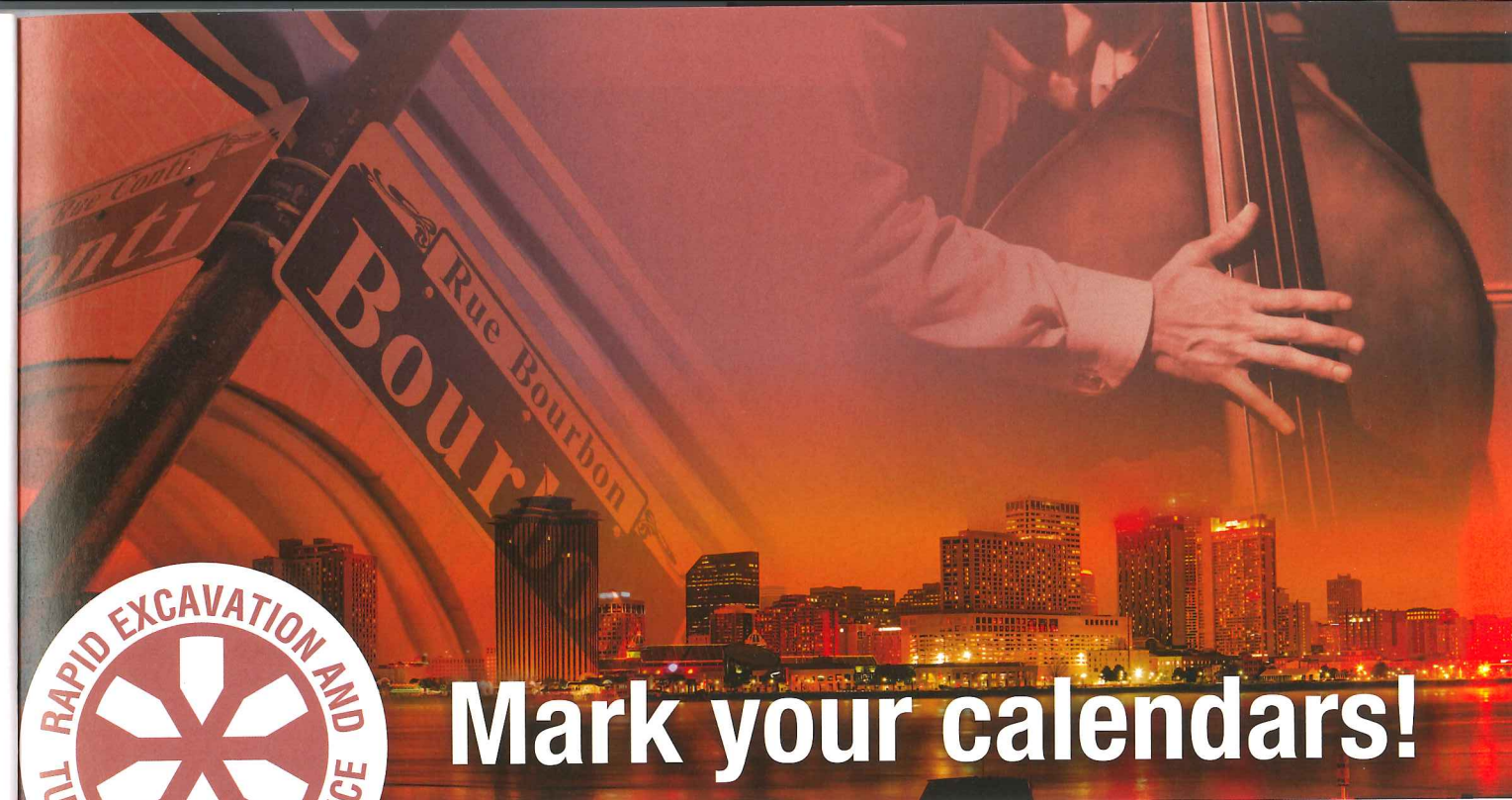
Crossrail exhibit at London Transport Museum

GREAT BRITAIN — A new exhibition Breakthrough: Crossrail's tunnelling story, gave visitors an experience of London's hidden subterranean landscape when it opened to the public on the 1 February at the London Transport Museum in Covent Garden.

The exhibition brings to life the sheer scale of the work being done to deliver Crossrail, the new railway that will bring a 10 per cent increase to the city's rail capacity. Visitors will experience the tunnel environment, learn about the way Crossrail is burrowing under London, play interactive tunnelling games and hear the first hand experiences of those who work underground.



Workers on the Harbor Siphons project



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Exhibit and sponsorship opportunities are now available at: www.retc.org.

Registration Opens April 1, 2015

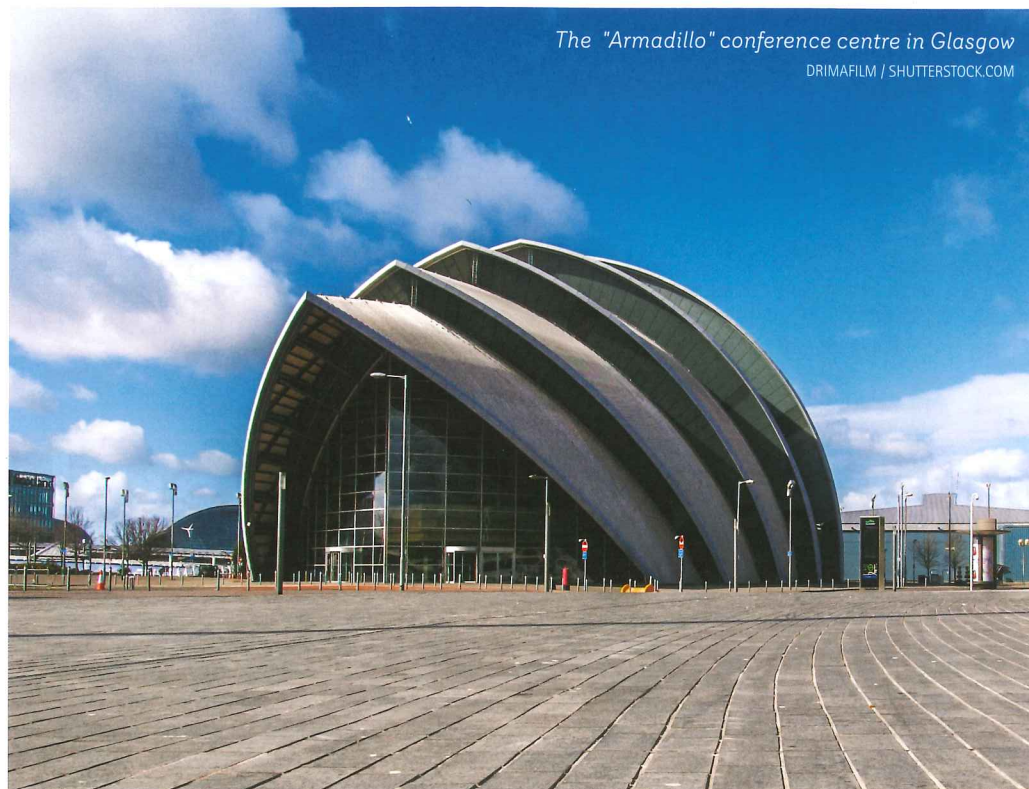
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www.retc.org



The "Armadillo" conference centre in Glasgow
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FREE HEALTH AND SAFETY CONFERENCE IN SCOTLAND

GREAT BRITAIN — Scottish businesses will get the opportunity to learn more about how to protect their employees from the risks of being injured or made ill at work at a free educational conference being organised by the British Safety Council at the Health & Safety Scotland exhibition at the SECC Glasgow on 22-23 April 2015.

As the official education partner for the free-to-attend exhibition, the British Safety Council has arranged for expert speakers from the health, safety and legal worlds to provide advice to employers on some of the most effective ways of managing risks to people's health and safety at work. The presentations will cover topics such as recent and forthcoming changes to UK health and safety legislation; creating a positive safety culture at work; and ensuring the safe activities of a company's contractors.

Neal Stone, acting Chief Executive of the British Safety Council, who will be chairing both days of the conference, said: "The seminars will shine a light on some of the critical health and safety challenges facing businesses, the public and third sectors in Scotland today and seek to improve employers' understanding of how to prevent workplace injury and ill health, which is estimated to cost the UK £14.2bn each year."

One of the presentations on the first day, Wednesday 22 April, will be on how to ensure competence, commitment and leadership in

health and safety. Rosemary Campbell, an experienced health, safety and environmental consultant based in Scotland, will argue that in far too many UK businesses, basic and often inexpensive health and safety controls are lacking, and a dangerous "it'll never happen here" attitude persists towards workplace injuries and ill health.

Rosemary will explain the benefits of ensuring that all employees are committed to working safely, and will explain ways of challenging the "complacency which can arise from nothing very serious happening, yet".

Day two, Thursday 23 April, will feature an interactive mock criminal health and safety trial hosted by leading lawyers from the Scottish offices of international law firm Pinsent Masons LLP.

A fictional construction firm and its managing director will be "prosecuted" following a serious workplace safety incident, and the MD, the injured worker and the investigating Health and Safety Executive inspector will all be cross-examined by real-life lawyers.

The assembled audience will then be invited to deliver the "jury's verdict".

Other presentations over the two day event include an update on recent changes to health and safety legislation and trends in enforcement; advice on managing contractors; and guidance on carrying out surveys of workplace noise levels.

DMT celebrates quarter first century

GERMANY — DMT is celebrating the 25th anniversary of its brand. DMT was founded in 1990 to tap into new markets outside of the German coal industry. Today DMT operates as a provider of engineering and technical consulting services for the oil and gas market, mining, infrastructure and the process and mechanical engineering market. DMT's roots lie in the early hard coal industry surrounding the Rhine and Ruhr rivers and the founding of the organization Bergamtskasse Grafschaft Mark in 1737. At first solely responsible for the finances of the supervisory mining authorities, a merger in 1864 formed the Westfälische Berggewerkschaftskasse (WBK) and greatly expanded the company's focus to include miners' training, research, testing, and consulting and subsequently developing it into one of Germany's research and testing facilities as safety in mines became more stringent.

Bouygues reveals new operating structure

WEST EUROPE — Philippe Bonnavé, who was this month appointed chairman and CEO of Bouygues Construction, has appointed a new operating structure. Olivier-Marie Racine has been appointed Deputy CEO, with responsibility for Bouygues Bâtiment International and Bouygues Energies Et Services. Jean-Philippe Trin has been appointed Deputy CEO, with responsibility for Bouygues Travaux Publics, DTP and VSL International. Building operations in France and Western Europe (excluding the UK), also under the supervision of Philippe Bonnavé, are directed by: Pascal Minault, CEO of Bouygues Entreprises, and Bernard Mounier, CEO of Bouygues Bâtiment IDF.

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BREAKTHROUGH AT GROSVENOR PROJECT

AUSTRALIA — A TBM broke through on the Grosvenor Project, a coalmine, in Queensland last month. This marked the end of tunnelling works at the mine, which was the first in Queensland to use TBM technology.

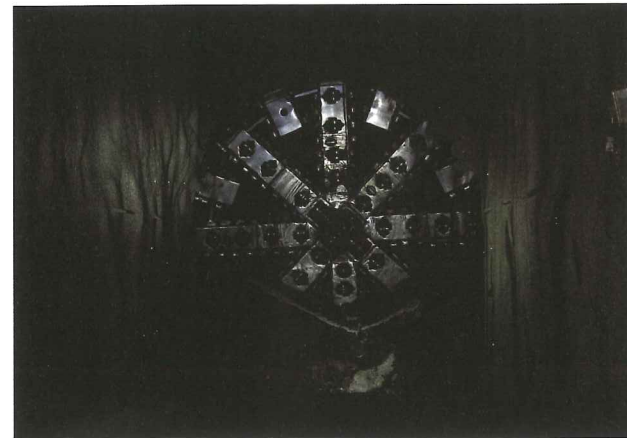
Mine owner Anglo American Coal opted for an 8m-diameter Robbins dual mode rock/EPB TBM to bore two declined access tunnels at grades of 1:6 and 1:8. One of these was for conveyors and the other for people and equipment.

The TBM was optimised for hard rock and mixed ground excavation in geology ranging from soft clay and soil to sandstone and basalt. The two-stage screw conveyor worked in both ground conditions to draw muck from the tunnel face. Two sets of shields were built for the TBM's "Quick Removal" system, and were detached from the machine at the end of each blind tunnel to be left in the ground for constant support, a requirement in Australian tunnels. The inner

core components of the TBM were then retracted out of the segment-lined tunnels on specially designed transport dollies.

The machine began boring the conveyor tunnel in December 2013, and after completion in May 2014 was successfully retracted and transported to the second tunnel site. The machine was then re-commissioned for the people and equipment tunnel in November 2014 with a new set of shields. Once excavation commenced, boring was completed in 88 days at an average of 10.9m per day, with a best day of 25.2m. The bore itself was similar to the first, with few challenges encountered other than elevated methane gas levels that required several temporary stoppages in order to safely remove the gas from the tunnel.

The team is now preparing the machine for its final retraction and rollout, and it will be on the surface in less than two months. The TBM will then be stored onsite for future Anglo American



The TBM at breakthrough

mining projects.

The "Crossover" designation is new for Robbins dual mode TBMs, and according to the company will be used for all such projects going forward. The type of TBM used at Grosvenor is now known as an XRE, standing for Crossover between Rock/EPB. Other types of machines are designated the XSE (Crossover between Slurry/EPB) and the XRS (Crossover between Rock/Slurry). The XRE TBM was picked over

the traditional roadheader method for several reasons, including excavation speed and tunnel maintenance. The machine excavated at a rate approximately ten to fourteen times faster than a roadheader. The segmental lining also lowers maintenance requirements.

Robbins president Lok Home said the increasing number of projects being excavated in mixed ground would result in a swell in interest for these types of machine.



The TBM prior to excavation

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Murphy hires new regional operations director...

GREAT BRITAIN — Contractor J Murphy & Sons has appointed Peter Walsh as operations director for the 'London and South' region. Walsh will be responsible for the civil engineering business, including rail, tunnelling and piling.

A Murphy spokesman said that Peter's appointment was part of a number of changes within the company for the next phase of development.

Darren Ramsay, managing director for the London and South of England region commented: "I am very pleased to welcome Peter to Murphy. He joins the company at a time of transition and growth – and his diverse and extensive experience in major projects management and people leadership will be instrumental in helping drive growth in these key sectors.

"Peter will be focused



Peter Walsh

on the safe and sustainable development of these businesses in line with the company's future growth plans. His role will also be key in driving innovation forward, strengthening collaboration with clients, and leading our operations in line with our never harm culture."

Peter joins Murphy from VINCI where he has held a number of senior positions during the last 17 years. He has a wide-ranging experience in major rail and other infrastructure operations.

...and appoints strategy and business development director

GREAT BRITAIN — J Murphy & Sons has appointed Bill Merry as its new Strategy & Business Development Director, with executive responsibility for business development strategy.

CEO Matthew Behan said: "I am delighted to welcome Bill to the team. With an impressive track record and extensive experience, Bill brings a wealth of knowledge and leadership credentials to Murphy.

"Leading our expansion plans for the growing market, Bill will use his extensive experience across the UK construction market to drive client relationships. He will also strengthen the company's position in its core markets, building on our excellent work in the infrastructure sector to date."

Bill Merry commented: "I am delighted to be joining such a respected



Bill Merry

brand and market leader. The pace of the economic recovery and the predicted rise in investment for the infrastructure market presents Murphy with an opportunity to significantly build upon and broaden its current portfolio and I very much look forward to helping with this.

Previously Business Development Director of Balfour Beatty Engineering Services, Bill has held a number of senior strategic and business development roles at Kier, Ballast Nedam and Walter Lawrence.

LONDON UNDERGROUND CYCLE PATHS

GREAT BRITAIN — A concept for a network of subterranean pedestrian and bike paths has won a London Planning Award. Topping the 'Best Conceptual Project' category, The London Underline project would run through disused London Underground tunnels and other unused infrastructure.

A spokesman for Gensler, the design company responsible, said they were embracing a movement towards alternative transportation and growing urban curiosity.

The routes would be paved with energy-generating Pavegen tiles, which convert the kinetic energy from impacts (such as footsteps) into electricity.

Ian Mulcahey, co-director of Gensler London, says "Now that London has reached the highest level of population in its

history we need to think creatively about how to maximize the potential of our infrastructure. The adaptation of surplus and underutilized tube and rail tunnels could provide a quick and simple addition to our infrastructure network."

With current pressures on London to cope with future transport capacity for pedestrians, cyclists and tube users, London is in desperate need for new types of public and community space, as well as affordable retail, commerce and entertainment spaces. Subterranean spaces present an excellent option for new uses.

Gensler designer Trevor To said, "Gensler's proposal brings back an ignored part of the city through the collective efforts of its citizens. By harnessing the kinetic energy of every one's footsteps, a whole new urban space is unlocked underneath the city. This self-sustaining approach to urban infrastructure is key to a carbon-neutral community, and London could lead the world once again in merging tradition with innovation to create a better future."

The electrical supply to support this underground park would be generated from foot traffic at a transit station such as Charing Cross or Holborn. Allegedly dubbed "Boris Bike Underground," The London Underground would also offer new sites for pop-up businesses, exhibitions, retail and event space.

Underneath the whole of London is an untapped surplus of disused space in subterranean infrastructure – tube tunnels, exchanges, stations, and reservoir chambers. We envisage, through the emergence of kinetic energy technology, London's acceptance of alternative transport, and Londoners' urban curiosity, that a new network of pedestrian and cycle links could be made by regenerating this infrastructure.



The Gensler cycle concept

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EUROSTAR SALE SLAMMED

The UK Government faces criticism from the political left as it proposes to sell its stake in the Channel Tunnel rail provider, the latest in a series of privatisations



The Government has announced that it intends to sell its 40 per cent stake in the cross-Channel train operator Eurostar for GBP 757M (USD 1.14bn). The buyer is Anglo-Canadian consortium Patina Rail LLP, which will be the only private stakeholder, the remainder of the shares being held by French and Belgian national railway companies.

If the sale goes ahead, the Eurostar stake will have been sold just two years after it began making a profit, the UK earning a GBP 7.4M (USD 11.14M) dividend last year on Eurostar profits of GBP 52M (USD 78.27M). This has come following a decade of steadily increasing passenger numbers following a disappointing initial uptake in the 1990's, and dividends are expected to further increase.

Chancellor George Osborne said that the cash injection from the sale would secure Britain's future, as it allows him to make a dent in the national debt. Which stands at GBP 1.4 trillion (USD 2.11 trillion). With annual interest payments of

Above: The Eurostar became profitable two years ago
TUNGCHEUNG / SHUTTERSTOCK

about GBP 43bn (USD 65bn).

Mary Creagh, Labour's shadow transport secretary, said: "Eurostar is a national strategic asset that is set to grow and to return increased profits to the UK taxpayer with new routes to Geneva, Lyon, Marseille and Amsterdam.

"After the staggering incompetence of the Royal Mail sale fiasco, which lost taxpayers GBP 1bn (USD 1.5bn), people will worry that this is yet another rushed and undervalued sell-off. Lord Myners is still conducting his review into government privatisations after Royal Mail, and ministers should await his report before any sale begins.

"The National Audit Office should urgently conduct a value-for-money inquiry before this sale proceeds. We must ensure that taxpayers are not ripped off again by bungling ministers and poor financial advice from the City."

Manuel Cortes, leader of the TSSA rail union added: "George Osborne, because of his outdated belief in unvarnished Thatcherism, is once again selling off the family silver for short-term financial gain. The reason that France and Belgium already own the majority stake in Eurostar is that they believe in running a publicly owned railway for the benefit of everybody."

Mick Cash, leader of the RMT rail union, said: "This is a gross act of betrayal of the British people by a right-wing Government hell-bent on selling the family silver."

The Government has announced a target of GBP 20bn in sales from a campaign of privatisation up to 2020

Alex Conacher



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- 1 TBM Herrenknecht M-365 M, year 2001, Ø 3.11 m
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- 1 DIESEL locomotive SCHÖMA CFL 200 DCL, track 900 mm
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A QUESTION OF TERMINOLOGY

Dear Sir,

Some remarks made by Gary Brierley in his article 'Austrian Tenacity' (January 2015, p.47) reminded me of a comment made by Alan Muir Wood at the Tuncon Conference in Johannesburg, in 1970 (yes, 45 years ago). A paper had just been presented by an Austrian engineer in the NATM, and in the period for discussion Alan made the pithy remark that there was nothing new or particularly Austrian about NATM!

In his book 'Tunnelling - Management by Design', published 2000, he devotes most of page 27 in explaining his views more fully.

Isn't it time that we tunnellers, and Tunnels and Tunnelling, stopped using the term NATM, and used wording such as "Sequential Excavation & Support"?

Tony Boniface
Cape Town

Editor: Muir Wood said he wrote the book because, in his view, "tunnelling has become a fragmented process, excessively influenced by lawyers' notions of confrontational contractual bases. This prevents the pooling of skills essential to the achievement of the promoters' objectives.

[This book] seeks the reversal of this trend."

For readers' convenience, the passage by Alan Muir Wood (2000) follows on. Notes in square brackets are annotations by Muir Wood on Rabcewicz.

Muir Wood: *The major steps forward in tunnelling occurred in the 1950s with the principles coupled with growing understanding of the behaviour of jointed rock, the availability of new techniques in rock bolting, the use of rock anchors and the application of sprayed concrete (Shotcrete being a trade name) and, most importantly, the opportunity to test out new ideas with growing confidence in practical tunnelling. Two noteworthy early developments were in Switzerland, 1951-55, Using Shotcrete for the Lodano-Losagno Tunnel for the Maggia hydroelectric project and the Snowy Mountains Hydroelectric Project in New South Wales, Australia from 1952 (Lang, 1961, Andrews et al. 1964, Dann et al. 1964, Moye 1965). Many others in many other countries have grasped the essence of the principles and applied it with success.*

Rabcewicz coined the title 'New Austrian Tunnelling

Method' (NATM) in 1962 (Rabcewicz 1964) with an explanation:

"...the author carried out during the (1939-45) war a new method called the 'auxiliary arch' which consisted of applying a relatively thin concrete lining [a conventional in-situ lining of the time would be an unlikely candidate for the 'observational method' then described] to the rock face as soon as possible, closed by an invert and intended to yield to the action of the protective zone [the name given by Rabcewicz to the rock adjacent to the tunnel]. Deformation of the auxiliary arch was measured continuously as a function of time. As soon as the observation showed a stabilising trend of the time/deformation curve, another lining called the 'inside lining' was constructed inside. The method can be considered as the real predecessor of NATM as it comprises all the integral factors with the exception of modern means of surface stabilisation."

If the approach (it is not a method) had retained comparable simplicity of principle, the term NATM would be more generally accepted at the present day as defining a valuable step in furnishing the tunnel

engineer's tool-kit (Müller 1978, Müller and Fecker 1978). But the succeeding generation of Austrian tunnelling engineering could not forbear to invest the principles in an impenetrable shroud of complexity - and downright nonsense - possibly with an aim of combining market penetration with apparent academic respectability. Examples include the extraordinary variety of definitions of 'ground rings' (the 'protective zone' of Rabcewicz), i.e. the zones of rock naturally stressed by excavating the tunnel, which girdle - or in some exigencies appear only partially to girdle - the tunnel. In reality, any opening of the ground causes a degree of ground support to be conferred by circumferential stress of the ground. The official definition of NATM, issued by the Austrian Society of Engineers and Architects reads: "The New Austrian Tunnelling Method constitutes a method where the surrounding rock or soil formations of a tunnel are integrated into an overall ring-like support structure. Thus, the formations will themselves be part of this supporting structure."

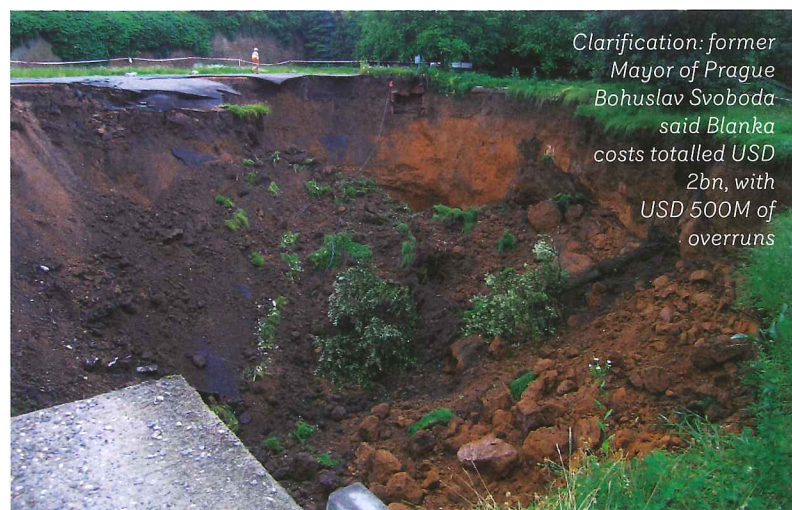
This, as Kovári (1993) explains, is a universal consequence of tunnelling.

On shaky financial ground

Dear Sir,

Surely there is an error in the insurance article in your January 2015 edition (p.45) where it is stated that costs related to the Blanka Tunnel passed USD 2bn this would be the largest loss in tunnelling history. Munich Re did a paper on the largest tunneling losses in History (Blanka is on their list but with no value) and put their estimate of the Insured losses on them you can find this on the IMIA website, admittedly Insurance won't cover all the losses (especially often the delay costs) but some of the more spectacular losses are lower than this.

Michael Spencer
Marsh - Global Construction Practice



Clarification: former Mayor of Prague Bohuslav Svoboda said Blanka costs totalled USD 2bn, with USD 500M of overruns

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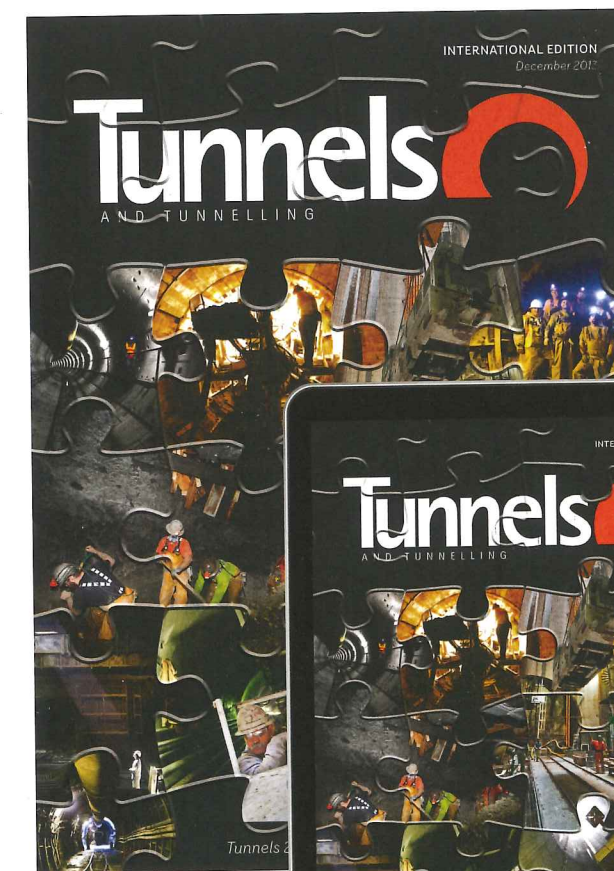
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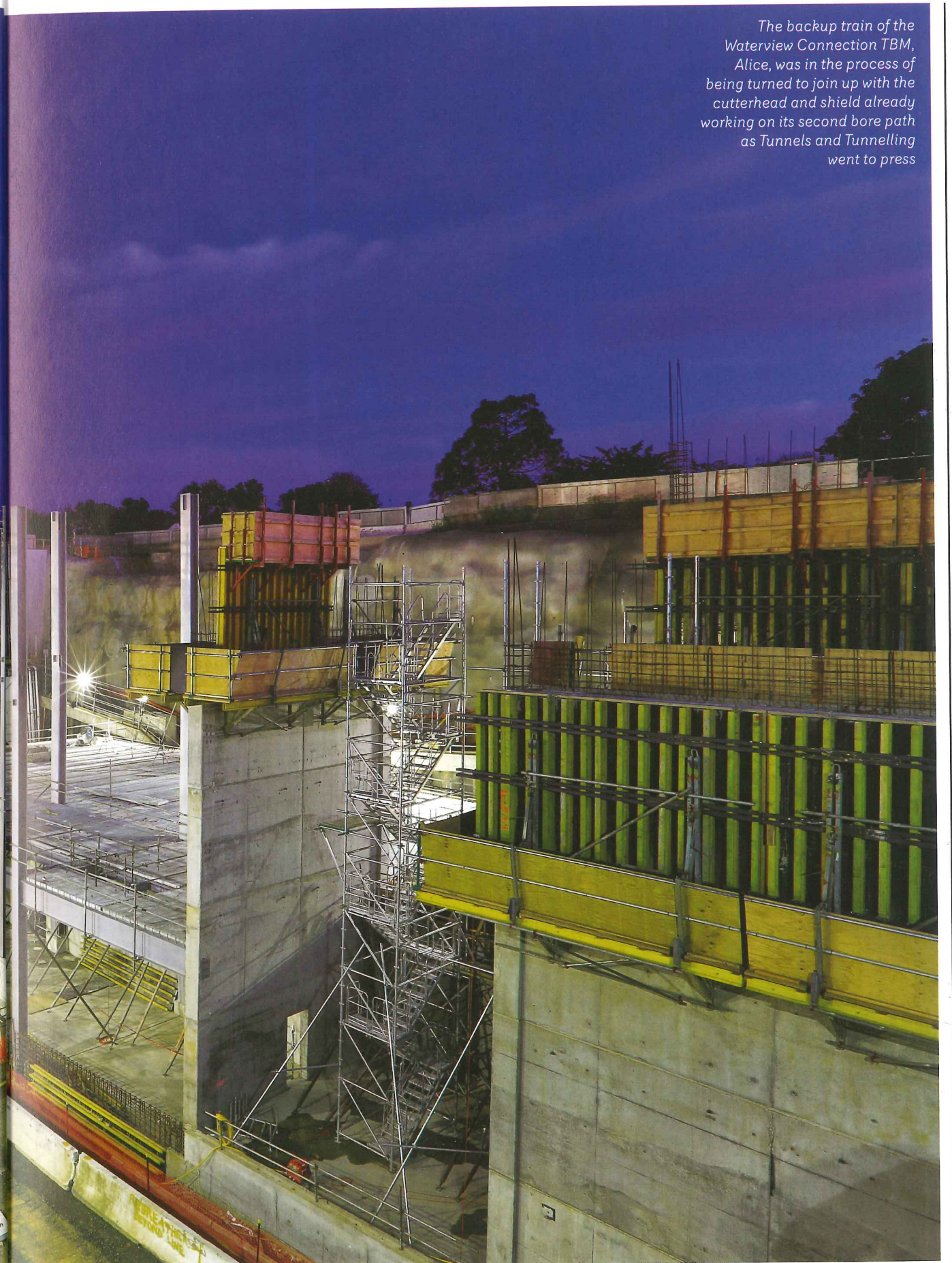
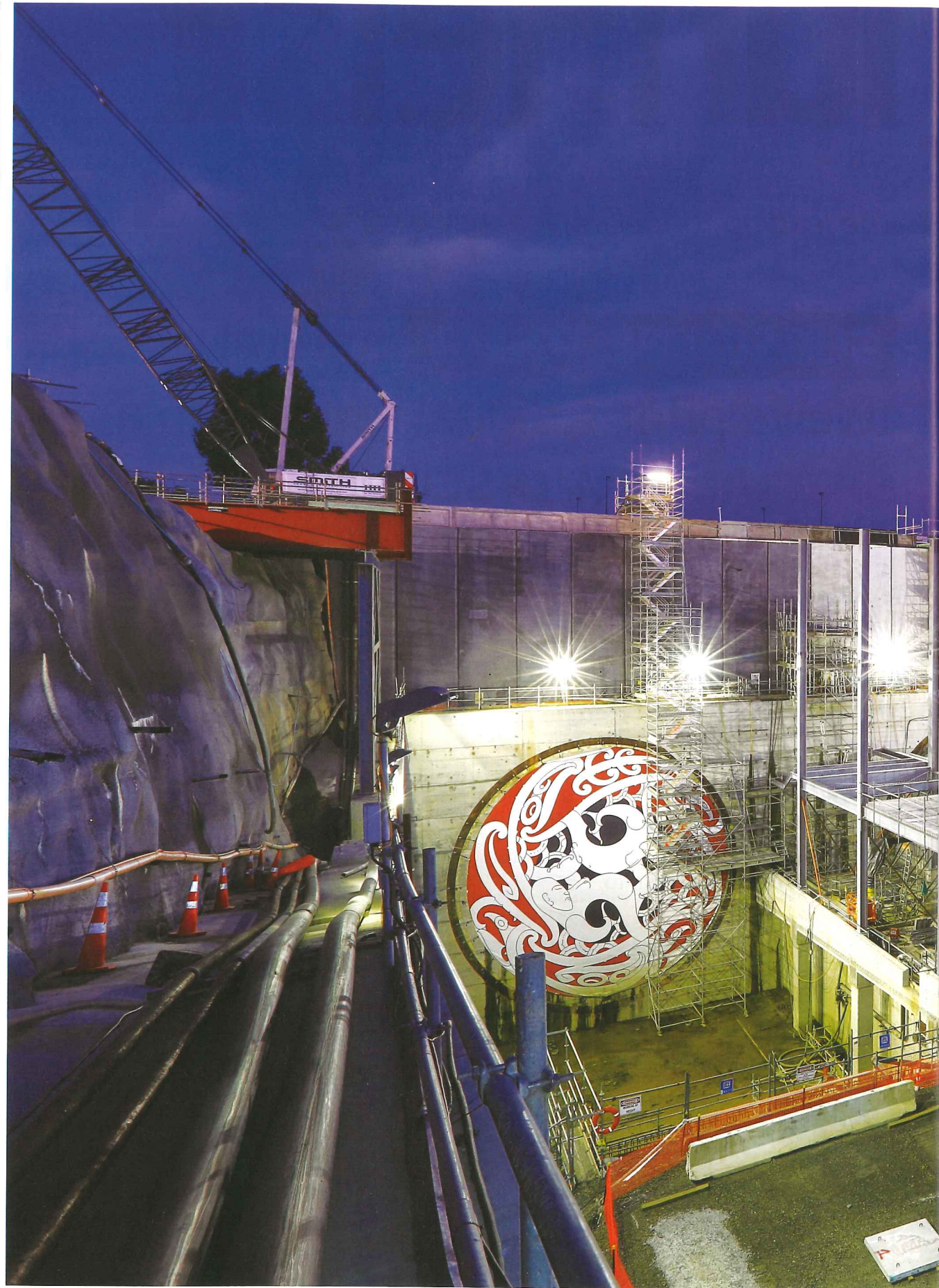
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The backup train of the Waterview Connection TBM, Alice, was in the process of being turned to join up with the cutterhead and shield already working on its second bore path as Tunnels and Tunnelling went to press



ROLLING, ROLLING

Conveyor use as a mucking system is spreading almost to the point of ubiquity, according to manufacturers. Technical journalist **Keren Falwell** reports

A TUNNEL project's progress is only as fast as the ability to remove the spoil, which is why conveyor systems are increasingly becoming the mucking out method of choice.

"Conveyor systems have proven themselves to be a very reliable means of muck removal," says Dean Workman, vice president, conveyor systems at Robbins.

And, he adds, there are "multiple advantages" to using a conveyor belt system.

"When the customer looks at the logistics of hauling the material with rail cars versus a conveyor system, they see that they can put in a lighter gauge rail, they can use smaller locomotives in the tunnel, and less ventilation is required because they're not running as many locomotives."

Terratec engineering manager and managing director Anton Jurasovic says the speed of muck removal provided by conveyors offers cost benefits, at least in long tunnels.

"Conveyors wouldn't be used if the tunnel is short as the high installation cost means there's not the opportunity to reduce the overall costs by speeding up the completion date. But on longer drives the main advantage is cost reduction of mucking out through reducing the time the full tunnel takes to be completed," he says.

Safety is also a big consideration.

"The more locomotives or muck trains you have in the tunnel, the greater the risk or an accident or derailment," says Workman.

FIRST CHOICE

Now the use of conveyor systems has become accepted practice, he says.

"Around the world contractors have an understanding of the systems and how they work so you don't have the battle that we did 20 years ago. Then it was belt conveyors versus muck cars but

Below: Terratec Continuously Advancing Conveyor System on the Bangkok Metro Blue Line

H+E on track in London

London / Great Britain. Restricted spatial conditions necessitated by dense development, difficult infrastructure with extremely high congestion where faults triggered by work in the soil could cause full collapse, an ambitious schedule – these are only some of the factors which make realization of Europe's largest infrastructure project – the Crossrail in London – an extreme challenge for the planners and companies involved. Swift removal of excavated material is an absolute must for smooth operations. Which is why H+E is deployed in the new Crossrail tunnel.

Technical data:

- Tunnel Diameter: 6.20 m
- Min. Radius: > 580 m
- Mineral: EPB
- TBM Supplier: Herrenknecht
- Conveyor Length: 2,850 m
- Belt Width: 800 mm
- Capacity: 650 t/h
- Installed Power: 355 kW
- Belt Storage Capacity: 500 m horizontal (double stock)
- Installation: 2013



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Keren Falwell

Keren joins the Tunnels and Tunnelling team as a contributing editor this year



it's very rare now that we have someone ask what the advantages of the conveyor are over the muck car system. The mindset of the industry has changed," he says. "In my opinion, conveyors are now the favoured method of mucking out."

The introduction of a conveyor belt system behind a TBM has had a major impact on the tunnelling industry, speeding up the whole process and enabling world records to be set, says Workman, adding that the only time a conveyor needs to be shut down is when more belt is added.

Another perceived advantage of conveyor systems is their reliability and Workman says they are generally operational for 90 per cent of a project.

"One of our customers in New York said they never gave a thought that the conveyor would be operating. They just had to push a button and it ran," he says.

Originally conveyors were used for tunnelling or mining in hard rock applications but a major development in the last five to 10 years has been their use with EPBs.

"Initially everyone was hesitant because of the always changing consistency of the material but we have proved that the belt conveyor can be used successfully in EPB applications," says Workman.

No matter what the method of removing the spoil, EPB-produced muck needs to be treated before it's handled and there is now more work being done on the transfer point to minimise the



All: Various conveyor requirements have been accommodated

amount of clean-up required around the belt conveyor.

"With EPB you have to take into consideration that you'll have a different type of material than you'll be conveying in hard rock applications so you have to seal up transfer points," says Workman. "Sometimes you have a lot of water on the belt and even though the water can be carried on the conveyor, when it goes to a transfer point there's a big surge and splash and it can force the solid material out so you have to seal up the transfer points as much as possible."

COOL RUNNINGS

However, Jurasovic points out that manufacturers are addressing the potential problems posed by conveyors.

"Manufacturers have 'super elevated' the belt to negotiate curves smoothly to minimise spills, and belts are now typically sized to ensure they are not 'over filled', which also minimises spillages," he says. "Also belt guides are added to control belt tracking."

According to Workman, the two 90-degree curves in the



"Now the use of conveyor systems has become accepted practice."

Deep Rock Tunnel Connector project in Indianapolis, have probably made it "one of the most difficult alignments that a belt conveyor has ever negotiated".

"We've not only proved that [the technology] can go to very long lengths but [it] can negotiate some difficult alignments," he says.

One of the biggest issues for such a sharp curve, and for conveyor systems in general, is safety.

"Going through a curve the belt can come off the idlers and go across the tunnel. We're using a very high strength of belting so should it come off, the implications could be catastrophic so you have to make sure you design the system so that doesn't happen," says Workman.

This is done by locating the boosters in the right places to control the tension, which not only enhances safety, but the life of the system as well.

"If the tension is too high it can cause premature failure through the curve."

But maintaining the tension is one of the biggest challenges



Case one: Bangkok

- Bangkok Blue Line Extension, Thailand
- Year: 2012 – present
- Client: Italian-Thai Development PCL
- Tunnel diameter: 6.44m
- Tunnel length: 5,700m
- Minimum curve radius: 160m
- TBM type: EPB
- Belt width: 600mm
- Capacity: 450TPH

Terratec was contracted by Italian-Thai Development PCL to design, manufacture and supply the 6.44m diameter EPB TBM and continuous conveyor system for muck haulage behind the machine as it advanced. It is the first tunnelling machine on the project which involves the building of twin running tunnels of approximately 5.7km in total length beneath Bangkok's historic Chinatown and under the Chao Phraya River.

Geology includes soft to stiff clay, layers of dense sand and the drives are under a groundwater table of high hydrostatic pressure. The integral conveyor system is designed to operate 24 hours per day in a high humidity and temperature environment with abrasive dust, wet paste and wet TBM spoil. A team of Terratec engineers and operators were deployed to assist during the assembly and commissioning of the machine and conveyor system.

The maximum capacity of the conveyor is 450TPH (225m³/h), which is enough to handle the material evacuated by the 6.44m TBM at full performance.

The system can work with a maximum gradient of -3.5 per cent and a minimum curve radius of 160m. The conveyor system has to transport approximately 185,000m³ of material during the excavation of the tunnels.

90

Twin 90 degree curves have made the Indianapolis Deep Rock Connector Tunnel arguably one of the toughest conveyor-mucked projects

of a conveyor belt system, coupled with locating the problem when something does go wrong.

"One of the biggest issues for the contractor is that you have to be able to determine quickly where the problem is if you have a fault or if the system goes down. If a major component is damaged all of the belt is going to cycle through that problem area in a relatively short period of time," says Workman.

"Some of these systems are very long – sometimes 36,000ft (11,000m) – and you can't see all of it at one time."

In projects around the world Robbins has seen incidents where the conveyor belt has nearly split in two, creating project delays and additional costs.

"It takes a long time to replace a belt; you don't just go in there with duct tape and put it back together," says Workman.

So minimising the chances of a problem or failure is key, and this is where monitoring systems and alerts come in.

EARLY DETECTION

"Early detection is vital," says

Workman, adding that electrical monitoring and alert systems have become increa

"We monitor not only the temperature of the electric motors and gear boxes, but also the vibration of these units so you can determine if there is something occurring that could cause premature failure. We monitor the torque of all the drives in the system so you know that if one drive starts to pull harder than the others that alerts you that there is a problem in that area, either pulling on the drive or with the running belt structure itself," says Workman.

Davis Derby designs and manufactures electronic control and monitoring equipment, software and data logging systems.

"Our systems monitor virtually all aspects of the belt," says contracts manager Dave Poole. "It monitors the belt for alignment and tearing, and temperatures on the gear boxes and motors."

Now the company is developing what it describes as a "total conveyor monitoring system". With WiPAN each pull key is fitted with a wireless connection system to create a wireless network along the length of the conveyor. The system identifies which pull key has been activated and feeds the information via co-ordinator and ethernet back to the surface.

"All that data is available to someone sitting at their desk but it's like sitting alongside the conveyor," says Poole, adding that it allows managers to decide whether a problem needs to be addressed urgently or it can wait until the next maintenance slot.

"It gives you a lot more information and allows decisions to be made so you can maximise productivity and minimise downtime," he says.

"The last thing you want is a tunnelling machine that's going at full bore then suddenly you can't get the material out. That could have been foreseen and resolved during the maintenance schedule."

WiPAN is being trialled on two jobsites in the UK and is close to being fully launched. Future planned developments include wireless vibration and temperature sensing, says Poole.

Robbins designs its systems so that, in the event of a problem, components can be changed as quickly and easily as possible. However, during his career Workman has noted that on tunnelling jobsites attention to maintenance is sometimes not as good as it could be.

"Companies mining a product to sell



Above: At Turkey's Kargi HEPP, a worker pauses while a side-mounted conveyor works to remove mixed ground

are putting in a belt conveyor system for long-term operation, normally 10 years. A tunnelling contractor is looking at the conveyor system being in operation for as long as they're boring, which is usually a relatively short period of time," he says. "Mining companies really look at their conveyor and track and train their belts but in tunnelling that tracking and training is sometimes neglected and then you start to have problems with the system."

Having said that, conveyors are not a one-use-only system. Redesigned and modified, they can be used multiple times, as

with the conveyor on the Indianapolis Deep Rock project which is now in at least its fourth incarnation.

At the same time, conveyor systems are constantly evolving in line with feedback from contractors and as components improve.

"They have become longer and faster – and consequently – higher powered," says Jurasovic. "This enables more types and lengths of tunnels to be use conveyor mucking, and faster belts can carry more muck for the size of the belt."

He believes the next technological developments will be

Case two: Indianapolis

- Deep Rock Tunnel Connector, Indianapolis, US
- Start date: May 2011
- Completion date: May 2016
- Design: Aecom
- Contractor: Shea/Kiewit joint venture

The Deep Rock Tunnel Connector is Indianapolis' largest combined sewer overflow project. The Shea/Kiewit joint venture has completed excavation of the main tunnel and is nearing completion of a shorter extension tunnel using a refurbished 6.2m diameter Robbins Main Beam TBM.

The main tunnel stretches seven miles and the continuous conveyor system must travel through two 90-degree curves – the first time a Robbins conveyor has done so. In order for the conveyor to negotiate the sharp curves, Robbins' patented curve idlers were installed, which are self-adjusting to the load.

The system also includes a vertical belt up a 250ft (76m)-deep shaft, and a stacker conveyor for temporary storage of the muck on the jobsite.



Above: One of the longest continuous conveyors ever provided by Robbins, for the AMR project in India. Two sets of conveyors will extend up to 22km each in several flights

lighter and stronger belts, faster belt speeds, and better head pulley lagging materials, with higher co-efficients of friction than are currently available.

Robbins holds regular design review meetings and aims to make improvements "with each new system we do", says Workman.

"Also the electrical control systems are improving as the industry improves the components that are used – from cameras that you can remotely control underground for monitoring, to variable frequency drives; there are so many things taking place right now." ◉

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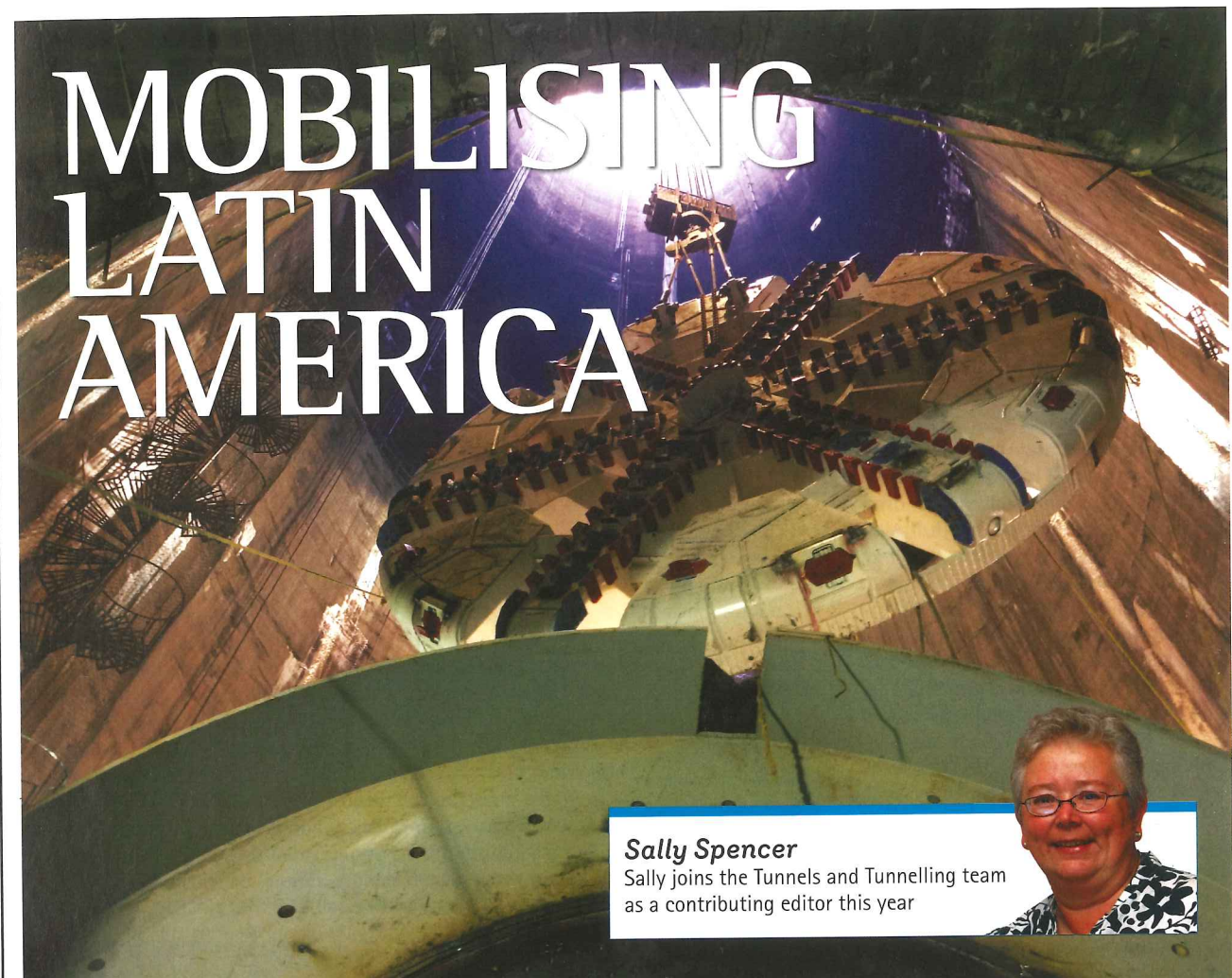
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MOBILISING LATIN AMERICA

Sally Spencer

Sally joins the Tunnels and Tunnelling team as a contributing editor this year



Major infrastructure projects across Latin America will mobilise both people and freight and provide much needed energy and utilities and the tunnelling sector is set to benefit. Technical journalist **Sally Spencer** reports

IN GLOBAL terms, while Latin America's 6.7 per cent market share of tunnelling activity is still dwarfed by that of Asia-Pacific, which accounts for a mighty 48.7 per cent, the industry is gaining real traction in many of the countries within the region.

Analysis by the Construction Intelligence Centre shows that the Latin American tunnelling and drilling equipment market was valued at USD 1.1bn in 2013, with Mexico accounting for the largest share at 46.9 per cent and Brazil, Colombia and Argentina following at 23.8 per cent, 19 per cent and 10.3 per cent respectively.

The Latin American equipment market actually decreased somewhat between 2009-2013, with its compound annual growth rate shrinking by 0.37 per cent but is expected to bounce back and grow by 5.3 per cent between 2013-2018.

Huge investment is under way in the region, said Javier Vaca, director of business development at FCC Construction. "With support from the Inter-American Development Bank (IDB) Brazil has planned investment of USD 260bn, Colombia USD 43bn, Peru USD 13bn and Chile more than USD 9bn," he

said.

"Projects such as high-speed and metropolitan railways, high-capacity urban and intercity highways, water supply systems, mining and power networks have all been identified across the continent," he continued. "There will be a huge demand for tunnelling expertise to provide complex underground solutions alongside traditional construction procedures."

By way of example Vaca cited the metro lines in Ecuador (Quito), Brazil (Sao Paulo), Colombia (Bogota) and Peru (Lima), as well as the La Línea highway tunnel connecting Colombia and Chile. The 8.6km tunnel is currently under construction and will be inaugurated in 2016.

Another standout project for Vaca, along with the rest of the tunnelling community, is the proposed Bioceanico Aconcagua Corridor, widely considered to be a "game changer for South America" and "the region's most important development in 100 years".

The project, which has the grand

Above: The cutterhead being lowered into place in the 150m deep launch shaft of Emisor Oriente's Lot 5 in Mexico City —the deepest TBM ever to be launched on a civil works tunnel in Mexico

ambition of providing a link between the Pacific and Atlantic oceans, will comprise a 204km electric railway from the city of Los Andes in Chile to Luján de Cuyo in Argentina.

This trans-Andean crossing will involve the construction of a 52km long, deep base tunnel that would be second in length to the Gotthard base tunnel in Switzerland. It will also include 29 side tunnels (10km).

Funding is still being sought for the estimated USD 3bn project and the IDB has been approached.

"There is a very clear interest in infrastructure that will build connections between countries and urban areas – anything that will increase the mobility of people and, ultimately, drive economies towards more growth," said Vaca.

"If these countries are able to make the tender process more dynamic and efficient and if they are able to realise some of the big projects in the pipeline, then the resulting connectivity and mobility for goods and people will blow the tops off many South American economies."

BRAZIL

Brazil is expected to see growth in demand for tunnelling and drilling equipment in the lead up to the 2016 Olympic Games, which take place in Rio. And the Brazilian government's second Programa de Aceleração do Crescimento (Growth Acceleration Plan) will also boost growth.

As Brazilian Tunnelling Committee president Hugo Cassio Rocha reported at last year's World Tunnel Congress, the country is witnessing strong investment in its infrastructure, including more than 42km of tunnels currently under construction and 150km more on the near horizon.

Current infrastructure projects include the Mario Covas ring road around Sao Paulo. The 170km, two-carriageway highway features several tunnels, the most recent of which are three tunnels totalling 5,700m on the 43.5km eastern section. Construction of the 44km northern section started recently and will feature seven twin tunnels, totalling 13.2km.

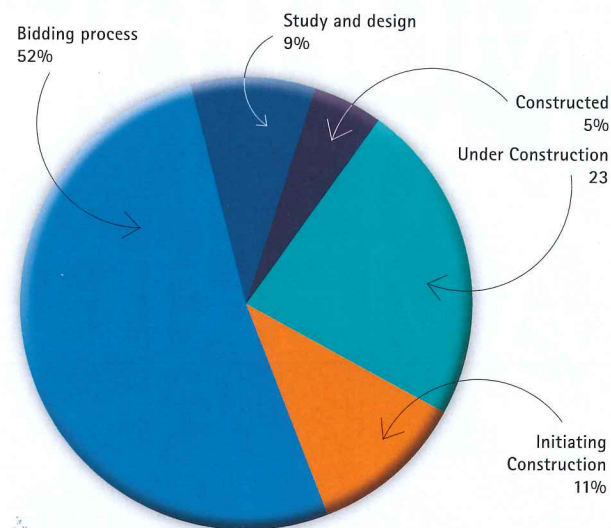
Metro lines are high on the agenda in the country. The Sao Paulo Metro has been growing continuously over the last decade and work is ongoing on several different lines.

Line Five is under construction and will be completely underground. It will total 11.8km in length, of which 1.5km will be excavated using conventional

Right: The workflow (by construction stage) of road tunnels projects in Colombia

Below: Sandvik enjoys a healthy local demand

Road tunnels by stage in Colombia



methods, 4.6km of single-track tunnels by two 6.9m diameter EPBMs, and 5.7km by a 10.6m EPBMs.

The line will have 11 stations, eight of which will be cut and cover and three of which will be built by the conventional method.

Rocha points to the extensive use of EPBMs and the cut and cover excavation for the stations as being significant. "Several stations are being excavated using multi-shafts with shotcrete support, a technique developed by Brazilian engineers and extensively applied," he said.



editor@tunnelsonline.info

What do you think? Send your views to the editor and join the debate



Line Six of the Sao Paulo Metro went out to tender as a Public-Private Partnership (PPP) and construction should begin this year.

The line will total 15.3km in length and will connect the Brasilândia station in the north-west of the city, to Sao Joaquim station downtown. The tunnels will be excavated primarily using 10.5m diameter EPB TBMs although conventional excavation methods will be used on granitic rock sections and in the deeper stations.

The expansion of Green Line Two in the direction of the north-eastern part of the city will feature 15km of tunnels, constructed by two TBMs.

Looking further ahead, the Roberto Marinho urban tunnel is being planned to ease traffic in the southern part of the city.

Two tunnels, each with three lanes, with a cross-section of 147m² and 15.7m wide have been designed. They will be excavated in soft ground, predominantly stiff clays and sandy layers of the tertiary basin of Sao Paulo and sections of residual soil of pre-Cambrian gneiss.

In Rio de Janeiro, Line Four of the Metro is being realigned and will be 14km long – all underground – with six new stations. The tunnels between General Osório and Gávea stations through the densely built-up areas of Ipanema will be excavated using an 11.53m diameter EPB TBM. Meanwhile, in the sections of rock between Gávea station and Jardim Oceânico, the construction process is drill and blast.

In other developments in the city, the Porto Maravilha Project will see the port area reintegrated into the city by demolishing viaducts and replacing them with tunnels.

Further afield, the Federal Government's Ministry for National Integration is planning to improve access to water for 12 million inhabitants in the Agreste and Backland regions of the states of Pernambuco, Ceará Paraíba and Rio Grande do Norte by integrating the Sao Francisco river with the water basins of the northern north-east region. Parts of the works are underground and will include the 19.5km Cunca I and II tunnels, which are currently under construction.

In the state of Minas Gerais, in the south-east of Brazil, a highway between Governador Valadares and Belo Horizonte will call for four tunnels – two 450m-long parallel tunnels, one 650m-long tunnel and a 750m-long tunnel. The state capital is also planning to build a metro system.

Perhaps one of the largest infrastructure projects in Brazil is the TAV high-speed railway system, which will run between Campinas, Sao Paulo and Rio de Janeiro. The proposed route will include 90.9km of tunnels in both rural and urban areas. The longest tunnels will be in the Serra das Araras mountains.

"The figures show that Brazil is investing in infrastructure



Above: Colombia is considered to be a pioneer of tunnel work in Latin America

and that underground works are now definitively on the list of viable solutions for meeting the needs of Brazilian cities," said Rocha.

"Brazil is waking up to the fact that underground works are, for the most part, the most appropriate solution."

MEXICO

High-speed rail projects also feature heavily in Mexico's infrastructure development plans, driven by its Federal Government.

For example, the Secretaria de Comunicaciones y Transportes (SCT) has two major high-speed rail projects on its books. One will run from Mexico City to Queretaro in the north, cutting a four-hour road journey to around 30 minutes by rail. The USD 4.5bn project will involve some tunnels, which will mainly be cut and cover, according to Roberto Gonzalez, general manager at the Robbins Mexico City office.

However, he added, the project has already hit problems, with the joint venture between Chinese and local contractors under intense scrutiny amid accusations of conflicts of interest and even bribery. The result is that the bidding process has to start over, with new bidders given a three-month deadline.

"It has created a lot of distrust in the bidding process, which is supposed to be transparent," says Gonzalez, adding that if this wasn't addressed "other companies will lose faith in the system".

The other high-speed rail project, which is already under way, runs from Mexico City to Toluca. It will include two parallel tunnels, approximately 7km long, which will cut through a mountain. Herrenknecht has supplied two TBMs for the tunnels, the excavation for each of which is around 9m diameter.

Probably the biggest infrastructure project for the SCT is the proposed new

Mexico City “mega-airport”, which was announced last September. Weighing in at USD 12bn, the 550,000m² airport, designed by Foster & Partners, won't actually feature any passenger foot or train tunnels but the entire structure will be serviced from below.

After a gap of about 20 years when there was little or no activity, the surge in tunnel construction – and particularly in mechanised tunnelling – in Mexico began in 2008 with Metro Line 12 in Mexico City. The extension to the 24km Line 12 is ongoing, although the 7km tunnel section was completed in 2012.

Robbins supplied the TBM, which at 10.2m diameter is the largest ever to have been used in Mexico and work was completed very quickly, says Gonzalez. And, in fact, the tunnel section is the only part of Metro 12 that is currently open. Gonzalez reports that the Spanish manufactured trains have proved to be incompatible with the rails.

“The trains work in the tunnels because they don't have such sharp turns, but the rest of it is closed. It's a mess and there are some other metro projects [planned] but with this scandal everything has been stopped.”

Having said that, however, Guadalajara is apparently considering building its first underground metro line. If it goes ahead it will pass under the city, including beneath the historic

Below: Four Robbins EPBMs will tackle difficult ground and highly urban conditions in downtown Fortaleza, Brazil



colonial area.

Less problematic perhaps, is the extensive work being taken by Conagua (National Water Commission) to improve the sewage system in Mexico City.

The 63km long tunnel was begun in 2009 and will be completed in 2018. The tunnel will run parallel to the existing 1960s one and will enable access for maintenance, with sewage flow (150m³/second) alternating between the two. The tunnel diameter is 7m and the excavation diameter is 8.9m and Robbins has supplied three TBMs for the project.

Conagua also has plans for a tunnel to ease pressure on the Dren General in the Valley of Mexico, which has flooded recently. Work should begin this year, initially on a 17km tunnel, with a 12km tunnel following in a second phase.

Projects are coming thick and fast from both the current administration, which was elected in 2013, and from private/public joint ventures and confidence is high, particularly when it comes to mechanised tunnelling. Amigos, the Mexican Tunnelling Association has promoted the method and run courses on it and, said Gonzalez, engineers are “more open to mechanised tunnelling, particularly for shallow tunnels under the city”.

A downside to the increase in activity in the country, he added, is competition from large international companies wanting a piece of the action. “Local contractors have to be more competitive and try to find a way to win bids,” he said.

COLOMBIA

Colombia has made significant advances in tunnel engineering and construction in the last decade, specifically with regards to tunnels for hydropower, highways and sewers, said Santiago Gutiérrez Ruiz, project manager at Ingetec.

“This has led the country to be considered one of the pioneers in this discipline in Latin America,” he said.

Ongoing projects include the aforementioned La Línea, which should be completed this year – although according to Gutiérrez the project has faced severe technical and financial issues and the contractor “has already exhausted all of the resources and run out of time according to the contract's schedule”.

Other work includes 22 tunnels on the road between Buga and Buenaventura (total length 8.8km); and 19 tunnels on the road between Bogota and Villavicencio.

Free trade agreements with North American, European and Asian countries, along with an increase in petroleum and mining activities have played their part in the economic growth of Colombia – trade that has spawned the need for a highways development programme cutting through the country's three mountain ranges.

These so-called fourth generation (4D) highways, which will be built within the next 10 years, include more than 125km of tunnels, of which approximately 96km will be more than 2km long. Most are currently under tender for the final design and construction and work should begin in the next couple of years.

Two big hydropower projects have been successfully completed recently, said Gutiérrez. The Sogamoso Hydropower Project has an installed capacity of 820MW, includes big diameter tunnels, excavated in sedimentary rocks of the tertiary, and features an underground station with three caverns.

The Porce III Hydroelectric Project, which was completed in 2012, has a 660MW installed capacity and features a 12.5km long headrace tunnel with a 10.5m diameter and a large cavern.

Three more hydropower stations, with installed capacity



between 400–2,400MW are being built, along with smaller stations (20–60MW) in the geologically complex Andes mountain range and will include large tunnels and underground caverns.

“Approximately 28km of tunnels for hydropower stations have been built recently and around 34km are currently under construction,” said Gutiérrez. “Moreover, four deep underground caverns have been built in the last few years and five are under construction.”

Improvements to the urban infrastructure in the future may include an underground subway system in Bogota. A 24km long subway line is under consideration, along with its second phase expansion up to 76km.

Sewer systems are also being developed, using the latest trenchless technology systems and specifically micro-tunnelling (pipe jacking), said Gutiérrez.

“The northern interceptor of the Medellin River, which is

under construction, has applied this technology. It is around 8km long and has diameters between 2.2–2.4m.”

The Tunjuelo Bajo interceptor in Bogota is also under way. It is around 8.3km long and is between 2.4–2.75 in diameter.

While continuing economic growth in the country may be hard to predict, some aspects of Colombia's economy have persuaded the tunnels sector that the level of work is sustainable, although it does have its detractors.

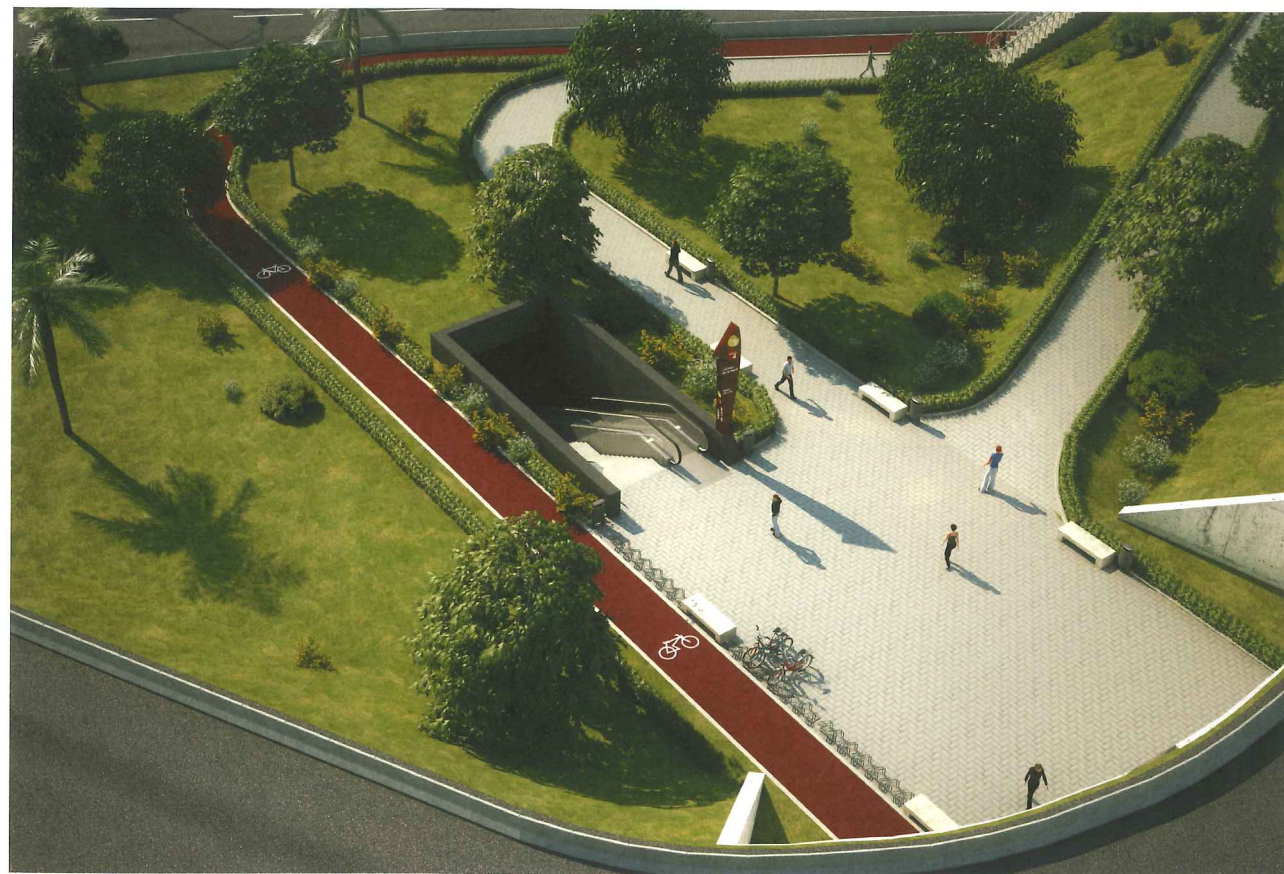
“There is a political appetite for big projects that can enhance Colombia's economy and tunnels are usually included within those projects,” said Gutiérrez. “However, there is great concern regarding the environmental and social impacts they may bring.”

“Furthermore, as underground geological and geotechnical conditions are hard to predict in the region, these types of projects are usually accompanied by overspending and delays, which bring litigation. This brings political unrest among legislators who may see these issues as a threat towards successful project completion.”

CHILE

With the recent boom in commodities, Chile's mining, energy and infrastructure sectors have seen significant investment, including in tunnels and underground projects,

All: The metro system in Lima, Peru will transform the city in 2020



according to Alexandre Gomes, general manager at Geoconsult's Santiago location.

While there has been a slowdown in construction in the country, the sector is expected to pick up this year and, in the medium term, transport infrastructure, including roads, railways and ports, is expected to maintain solid growth.

Construction is ongoing on new lines for the Santiago Metro. The USD 3bn project to build Lines Three and Six will feature around 37km of underground works, with 28 underground tunnels.

Meanwhile 9.3km of three-lane double tube urban road tunnels are under construction in the Américo Vespucio Oriente Highway project, while a further 4.3km are in review. The Ministry of Public Works (MOP) project, which is valued at USD 2bn, will complete Santiago's ring road.

Other road projects under way include the 12km Kennedy Road tunnel, also in Santiago.

Projects yet to start include, of course, the aforementioned Bioceánico Aconcagua Corridor, linking Chile and Argentina, but others are nearer to becoming a reality. The tender designs for both the Costanera Central urban highway and the second tube of the El Melón road tunnel are finished and the call for bidders is expected this year.

The energy sector should also see growth because the country needs a substantial boost to its capacity, said Gomes.

Construction is ongoing at hydropower plants at Alto Maipo (98km of tunnels, shafts and caverns), Angostura, Los Cóndores and Nuble, while the Arandanos y Nido de Aquila project is at the design stage, with tenders for construction expected in 2016. More hydropower plants are pending approval.

The mining sector, which has been one of the most active industries of late, is expected to stabilise and recover, said Gomes. Codelco, the country's National Copper Corporation is particularly busy at the moment. For example, 8.9km of access tunnels (two tubes) are being built at Codelco's New Mine Level in a USD 600m project; 28km of tunnels and caverns are under construction at the company's Nueva Andina mine in a USD 6.8bn project; and permanent infrastructure tunnels and works are being built at its Chugquicamata mine.

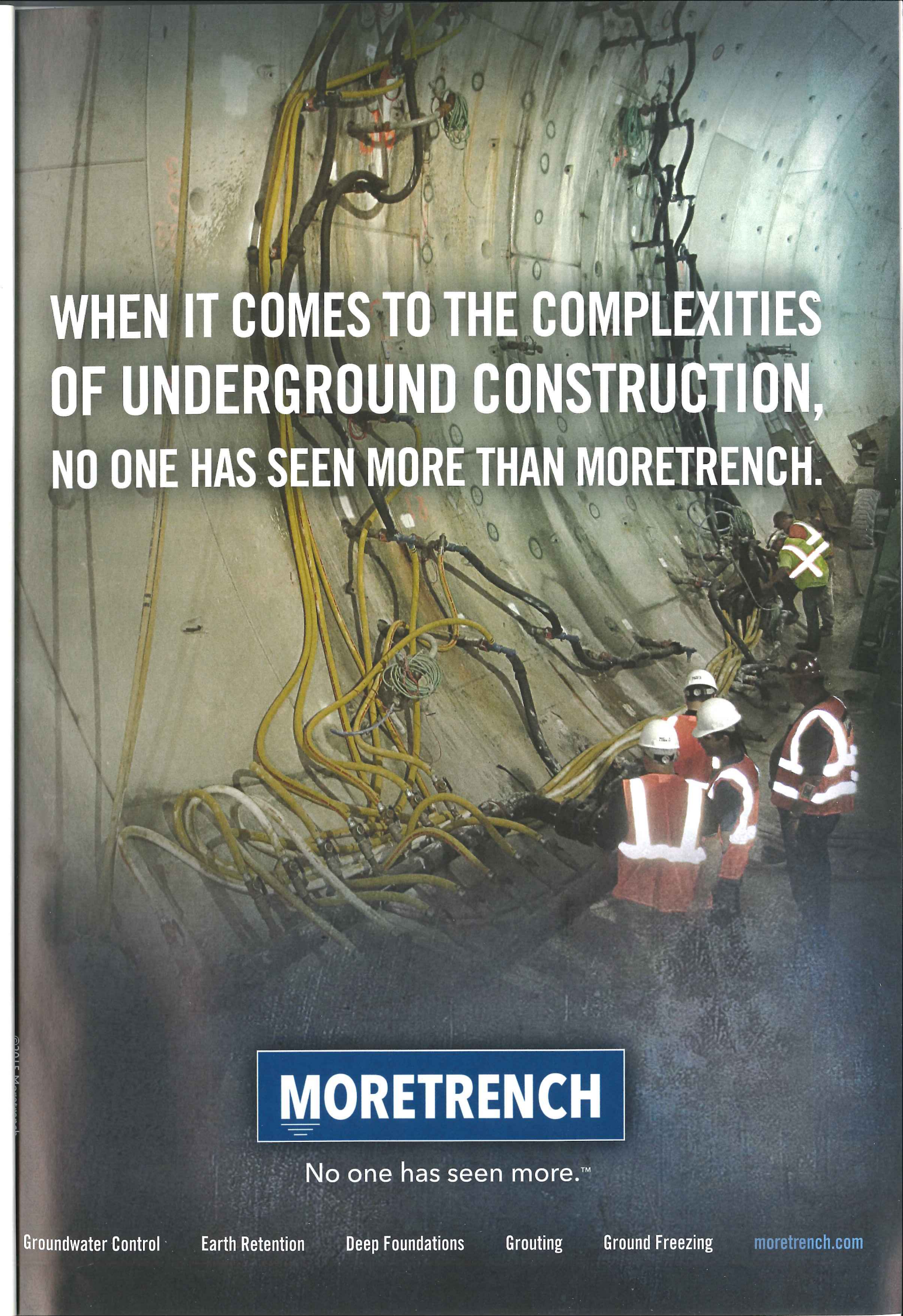
PERU

"The most important infrastructure project in the history of Peru," is how Javier Vaca describes the USD 4bn Lima Metro project, the construction of which started last August in a ceremony attended by President Ollanta Humala.

The underground railway will transform the city, sections of which will be turned into green spaces. It will carry more than 600,000 passengers per day who will save up to 90 minutes on their commute. The project is being led by FCC and ACS and works on Line Two include construction of 35km of metro and 35 stations, which are to be completed in mid-2020.

A branch of Line Four, which will go to the airport, is also to be built and will consist of an 8km long tunnel and eight stations. The first phase, between Ate and Vía de Evitamiento will be finished in the second quarter of 2016 and the second phase, between Óvalo Bolognesi and the Vía de Evitamiento, is due for completion towards the end of 2017.

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ARGENTINE SHAFT SAVIOUR

Tunnelling work for a water treatment project in northern Buenos Aires required shaft excavation in soft, sandy silt. When leaking joints hampered progress, the contractor chose to pursue groundfreezing, a possible first use in South America. **Joseph Sopko** and **Robert Chamberland** of *Moretrench* give this report

Joseph Sopko

Joseph is director of groundfreezing at Moretrench, based in the US



Robert Chamberland

Robert is a project engineer at Moretrench, and he has assisted Sopko since 1997



THE SISTEMA de Potabilizacion Area Norte project has been designed to transport and treat raw water from the Parana River to provide potable water for 2.5 million residents in Northern Buenos Aires. The project includes a 9.3-mile (15km) long, 11.8ft (3.6m) diameter bored tunnel, five access shafts and eight ventilation shafts. It also includes a water purification plant. The access shafts were completed using slurry diaphragm walls with jet-grouted stabilisation for bottom stability.

The tunnel was bored using two TBMs at depths ranging from 59 to 72ft (18-22m) below ground surface with the groundwater approximately 5ft (1.5m) deep. The generalised soil profile consisted of about 26ft (8m) of soft sandy silt overlaying strata of soft clay, firm sandy silt and very dense sand. Hard clay was present at depths near 160ft (48.7m).

Access Shaft Three was a 35.4ft (10.8m) diameter shaft constructed using a slurry diaphragm wall. The slurry wall was 98ft (30m) deep, well above the impermeable clay stratum. To provide sufficient bottom stability, jet grouting was used. The jet grout bottom seal was approximately 5m from the excavation invert.

During the initial shaft excavation undetected groundwater intrusion between the slurry wall panels led to inflows of substantial quantities of groundwater and soil. It was also possible that discontinuities within the jet grouted bottom were contributing to the shaft flooding. The prime contractor joint venture, Aguas del Parana UTE (ADP), flooded the shaft and attempted to seal the leaking joints with a grouting program, initially by direct injection of the grout using tremie methods. During the next 14 months excavation was hampered by continuing soil and water inflows. Repeated attempts of grouting, jet grouting and dewatering failed to facilitate excavation. The shaft was eventually backfilled to an elevation above the proposed tunnel crown.

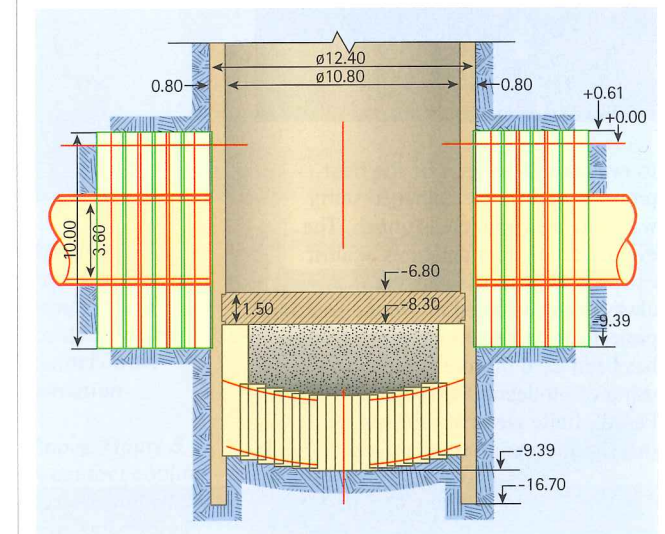
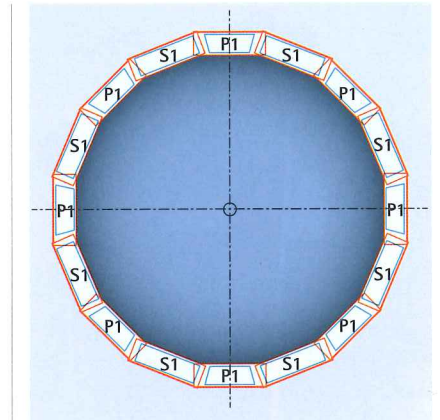
Following the backfilling with the lean concrete, the tunnel proceeded through the shaft and was eventually completed. With the finished tunnel penetrating both sides of the slurry wall, shaft excavation and completion was complicated. ADP contacted Moretrench American Corporation to evaluate the feasibility of ground freezing to provide temporary earth support and groundwater control to excavate and complete the access shaft.

Ground freezing offered several immediate solutions to the problems associated with leaking slurry wall panels and bottom instability following the excavation. A frozen soil cofferdam around the perimeter of the distressed slurry wall would conform to the shape of the panels and also seal any of the leaks by freezing the water in the joints. Additionally, the freeze pipes could penetrate well below the base of the slurry wall into the impermeable clay and provide bottom stability of the excavation.

A complication to the freezing process however was the fact that the tunnel was already in place. The presence of the tunnel would interfere with the drilling and installation of the freeze pipes on both sides of the shaft. More importantly, it would be necessary to ensure a completely frozen zone around the tunnel perimeter to prevent groundwater and soil inflows from around the tunnel and into the shaft. There were two approaches implemented to provide a frozen zone around the tunnel. The first approach was to drill and install angled freeze pipes under the tunnel as illustrated.

In order to ensure that the angled freeze pipes would reach the intended freeze zone it was necessary to establish the required azimuth to align the drill rig. Once the drill rig was set up on the azimuth, the mast was adjusted to the proper angle. After each individual freeze pipe was drilled and

Right: Figure 1, Access Shaft Three was a 10.8m diameter shaft constructed using a slurry diaphragm wall



Above: Figure 2, Section showing jet-grouted break-in and break-out zones and jet-grouted plug at the base of Access Shaft Three

installed, the deviation was measured with an orientable inclinometer. The actual locations of the freeze pipes were plotted at various depths with close attention paid to the elevations at tunnel invert and below. The actual freeze pipe coordinates at the invert were entered into a time dependent finite element heat transfer model.

This model evaluated and presented the ground temperature contours as illustrated in Figure 4.

The second approach used to complete a frozen zone around the tunnel was the installation of a cooling system inside the tunnel to keep the tunnel segments in the frozen zone well below freezing temperatures to compensate for the warm air inside the tunnel. This system is illustrated in Figure 5.

After the installation of the freezing coils insulation was applied and the system connected to surface refrigeration by drilling from the surface into the tunnel and circulating the refrigerated coolant from the two electrically powered freeze plants.

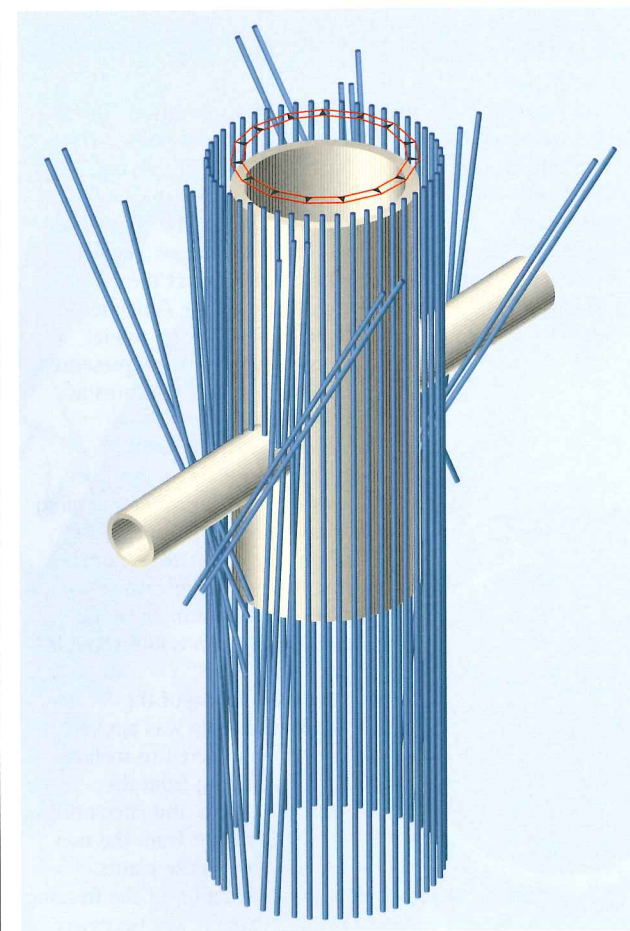
Before the installation of the freezing system was approved it was necessary



Left: 1.5m thick brick bulkheads were constructed in the tunnel to prevent material inflow in case of shaft failure

Below, both: Figure 3, Angled freeze pipes were installed around the shaft and under the tunnel

to evaluate the effects of the frost pressure against the damaged slurry wall and the completed tunnel. The evaluation of frost pressures against existing structures is an issue that must always be considered in ground freezing projects. A successful approach to that has been used on recent projects was the using of modeling the problem with the PLAXIS finite element program. Since this situation required evaluation of both



the tunnel lining and the slurry wall it was necessary to create a three dimensional model as shown in Figure 6.

Results of the analysis indicated that the pressures against the slurry would not cause any damage, even in the poor condition that existed. There was concern, however, that the frost pressures generated by the freeze pipes and the internal tunnel cooling system would generate pressures that could damage the tunnel lining segments. An internal bracing system was designed and would be installed concurrent with the drilling and installation of the freeze pipes.

The freeze pipes were installed using conventional mud rotary methods. A pilot hole was drilled to the required depth using a 5-5/8-inch (143mm) tri-cone. Each individual borehole was terminated only after verification that it penetrated into the underlying hard clay. The 4-inch (102mm) nominal welded steel pipes were then installed into the boreholes, pressure tested and surveyed for alignment using the inclinometer.

Following the drilling and installation of the freeze pipes the coolant distribution manifolds and mobile refrigeration plants were initiated. Two electrically powered refrigeration plants imported from the United States were used to chill the circulating calcium chloride brine to approximately -25°C.

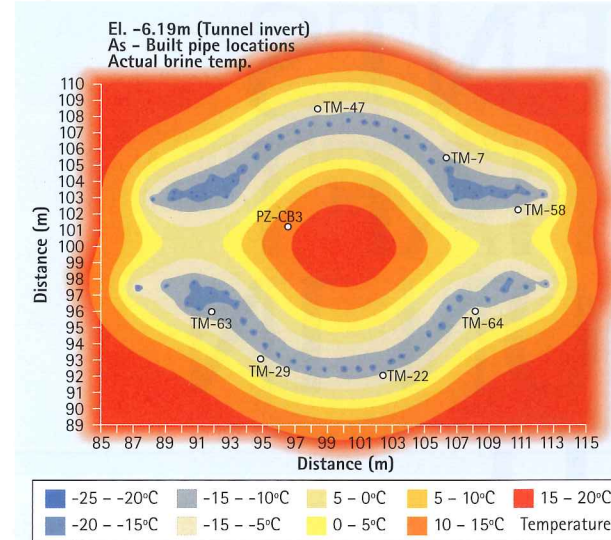
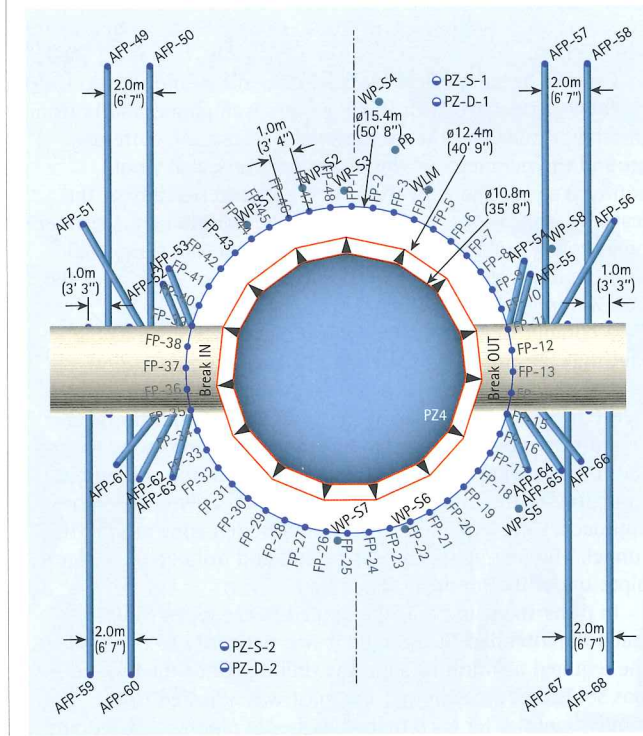
Concurrently with the surface work, the working inside the tunnel progressed. The first requirement was the installation and insulation of the internal cooling system.

The bracing system was then installed to protect the tunnel from the pressures generated by the freezing.

The bracing system consisted of a 250mm reinforced concrete ring installed outward from the shaft approximately 4.5m to coincide with the frozen zone.

In order to complete the shaft, it would be necessary to break into the tunnel once the excavation was completed. Due to the repeated unsuccessful attempts there was concern that a shaft excavation failure could introduce an unlimited quantity of water and flowing soil into the completed tunnel. ADP constructed two bulkheads on both sides of the shaft.

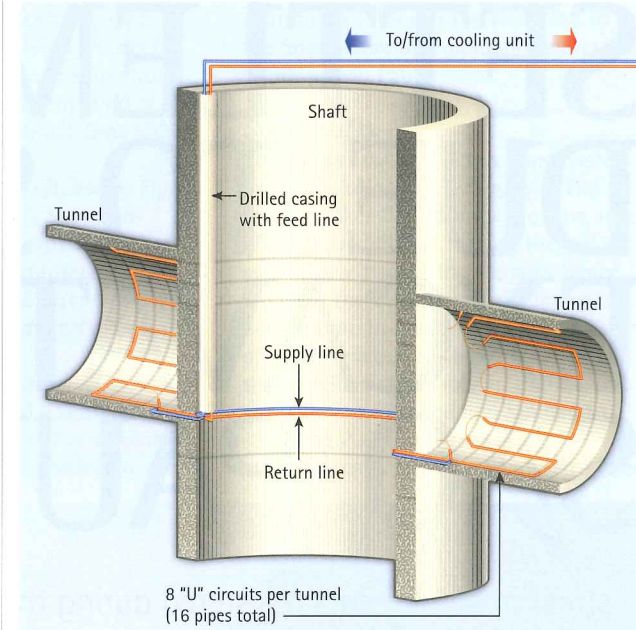
Each bulkhead was 1.5m thick constructed of masonry brick. Structural steel anchors were bolted to the tunnel segments to prevent sliding. Personnel access was provided



through an 800mm concrete pipe with a 25mm thick steel hatch.

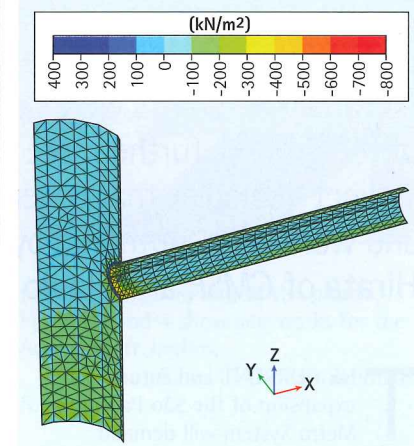
The freezing process was completed in approximately 80 weeks that was consistent with thermal modelling. An automated data acquisition and alarm system was used to measure ground temperatures, groundwater levels, the coolant temperatures and flow rates as well as freeze plant operating data. In most frozen shafts, where freezing is used as the initial ground support system, formation of the frozen earth wall is typically indicated by a rise in the water level of an internal piezometer or monitoring well. This is caused by the expansion of the pore water as it turns to ice.

On this project there was no internal piezometer to provide this critical information. As an alternative, the water inside the excavated portion of the shaft was pumped in approximately



Above, left: Figure 4, Ground temperature contours at the tunnel invert elevation

Above: Figure 5, A contact cooling system chilled the concrete tunnel segments to compensate for warm tunnel air



Right: Figure 6, Three-dimensional model to evaluate effects of frozen soil on the tunnel lining and slurry wall

Left: Installation of freeze pipes by conventional mud rotary drilling

one-meter intervals. During the pumping external piezometers were measured. There was no change or decrease in the groundwater levels in these piezometers indicating that the frozen earth cofferdam provided a positive cut-off and isolated the interior of the shaft. The shaft was subsequently pumped out completely with no indication of groundwater intrusion verifying the success of the freezing.

Excavation then proceeded to the tunnel invert as shown in the photos. The existing tunnel was then broken out and the final shaft constructed.

The project was completed with no damage to existing tunnel or issues with the frost pressures against the existing slurry wall, verifying the use of the three dimensional structural model.

This project represents the first time (to the authors' knowledge) that groundfreezing has been used in South America

SETTLEMENTS DUE TO SHAFT EXCAVATION IN SAO PAULO

A study of settlements registered during the excavation of several SCL shafts, built by the *São Paulo Metropolitan Company (CMSP)*, Brazil. Using data from the Monitoring System and Iterative Control of Instrumentation (SACI), a statistical analysis and empirical methodology to estimate settlements due to shaft excavation are presented. The analysed shafts were built using SCL and taking full advantage of the arch effect of the ground, furthermore the shafts have different diameters, depths and are built in distinct geologies that cover the main spectrum of the type of shafts built by the *CMSP* and worldwide. Authored by **Claudio Cabral Dias** of *Halcrow, CH2M Hill UK*, **Fernando Hirata** of *CMSP*, and **Flavio Kuwajima** of *Infra7 Consulting and Engineering*

THE CURRENT and future expansion of the São Paulo Metro System will demand the construction of several shafts to utilise as stations, accesses, emergency exits, ventilation, and construction support. Lately, shafts constructed by CMSP have used SCL as the primary support, which has proven to be a simple and fast constructive method, minimising settlements and economically competitive compared with traditional methods such as open trenches Bilfinger



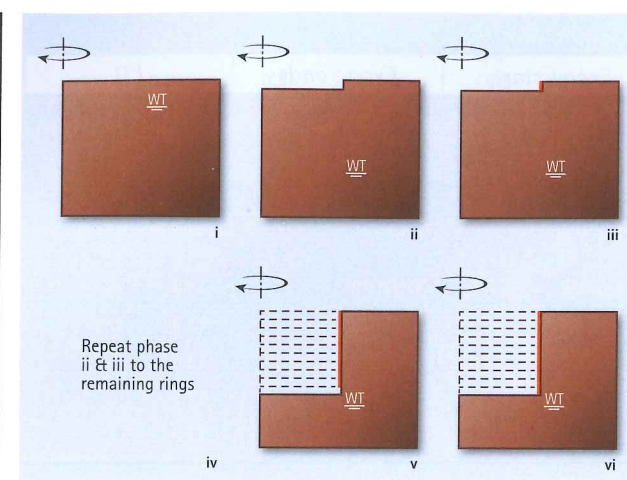
Below, left: Figure 1, Shaft names and locations in Sao Paulo

et al. (2012). The monitoring of settlements is a key aspect for the successful construction of SCL shafts, which can be considered as a Sequential Excavation Method (SEM) or NATM in the vertical direction. This paper intends to analyse some SCL shafts' instrumentation data, collected over the years by the CMSP. This study aims to obtain practical results for the design

Table 1. Summary information of the analysed shafts.

Shaft	MetroLine	Purpose*	Region
Incor	4	V.E.E.	Pinheiros
Jardins	4	Access	J. Paulista
Ferreira de Araujo	4	V.E.E.	J. Paulista
Domingos de Moraes	5	Access	V.Mariana
Joel Jorge de Melo	5	V.E.E.	V.Mariana
Magalhães	5	V.E.E.	V.Mariana
Jesuino Maciel	5	E.E.	C. Belo
Roque Petrella	5	V.E.E.	C. Belo
Alexandre Dumas	5	V.E.E.	S. Amaro
Paulo Eiró	5	V.E.E.	S. Amaro

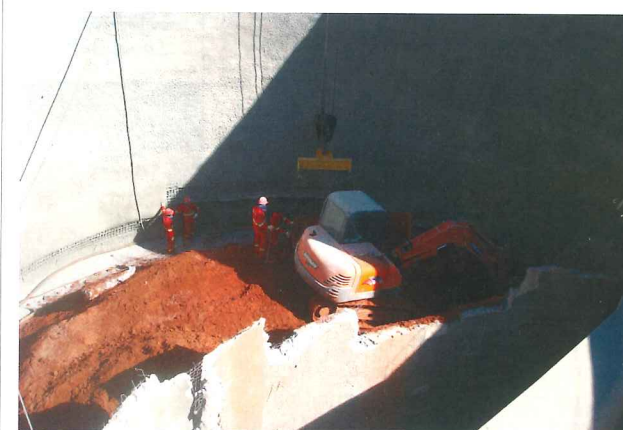
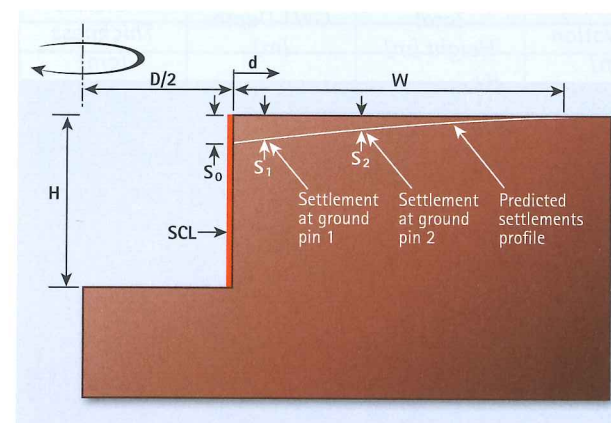
*E.E. = Emergency Exit; V.E.E. = Ventilation and Emergency Exit. Source: Authors



Left: Figure 2, Main phases for the sequential excavation of a shaft, Dias (2013)

Left, below: Figure 5, Shotcrete supported shaft parameters. Settlements in distorted scale

Below: Figure 3, Excavation and wire mesh installation



distribution: three in the West, five in the South-Central region and two in the South of São Paulo.

SCL Shafts

The shafts analysed in this paper were excavated using SCL as support. This method takes full advantage of the arch effect in the ground making the soil a constitutive part of the support, hence reducing the thickness of the lining to a minimum. In a plan view, the shape of the excavation should be circular or similar (elliptical) to maximise the arch effect and reduce bending moments.

Figure 2 shows simplistically the main phases of the excavation. To better



provide understanding of the phases, Figures 3 and 4 show site works for the Access Shaft Jardins.

The main phases of the excavation as follows:

- i. The 1st phase can involve ground water table (GWT) variations or not and the GWT dewatering can happen before, as shown in Figure 2, or while the excavation takes place. The construction of the capping beam can happensimultaneously with the dewatering;
- ii. Excavation of the 1st level (typically 1m height);
- iii. Application of the SCL to the 1stlevel;
- iv. Repeat phases ii and iii to the remaining levels, ending with the excavation of the last ring (v) and application of the respective SCL (vi).

Although conventional wisdom accumulated from experience with these structures has driven the use of a circular shape, the use of multiple-secant-shafts is increasing in the CMSP, for example the stations: Luz (Celestino et al., 2009), and Vila Prudente (Cecílio Jr. et al., 2010).

These innovations are due to architectural requirements and are made

of these structures.

The analysed shafts

Though there are dozens of shafts from CMSP, the authors decided to use three shafts from Line 4-Yellow and seven shafts from Line 5-Lillac, the most recent Lines built by the CMSP. Figure 1 shows the location of the shafts.

Table 1 presents the shafts' information, such as the relevant metro line, shaft purpose, and the regional

Above: Figure 4, Application of sprayed concrete. Both photos depict Access Jardins in October 2012

possible by combining tunneling and structural innovative solutions; recently completed the Adolfo Pinheiro Station required the construction of five SCL secant shafts. Brazil has been a pioneer of the innovations in the construction method presented in this paper.

SETTLEMENT DUE TO SHAFT EXCAVATION

The construction of shafts leads, like any other excavation, to displacements at the surface. The prediction of settlements in the design phase is imperative for checking the feasibility of the excavation and preparing the monitoring plan.

There is far less literature on ground movements associated with shafts than with tunnels. One explanation for this is related to the ground movements for shafts mainly occur on the construction site, thus other parties are often not affected. HS2 (2013), advances this as the main reason for the lack of accounts detailing ground movements due to shafts excavation having been published.

Settlement estimation methods

There are several methods to predict settlements. These are defined using data from real excavations instrumentation, they could be empirical, e.g. Peck (1969), or semi-empirical, e.g. Bowles (1984). The majority of the available methods refer to excavation in plane strain deformation, although the excavation of a shaft leads to an axisymmetric condition. While in open trenches, the support is built before the excavation starts, in SCL shafts it is done in phases, making the direct application of the estimation methods mentioned above difficult. Less movement of the soil is also expected as the ground arch effect is utilised.

Shaft evolutionary numerical calculations are being increasingly used and may estimate results close to the ones measured by the instrumentation, as example Kuwajima et al. (2004), but are not always available.

It is recognised that with time the numerical methods continue to gain prominence; we may also benefit from the results of the numerous instrumentation data already available and learn from it.

Local geology

The geology in the regions of the shafts can be divided into three major geological units: Precambrian, Resende and São Paulo Formations. Next, a simplified geological presentation of the materials found in the regions where the

Table 2 Characteristics of the shafts

Shaft	Excav. starts	Excav. ends	I.D.
Incor	09/2005	12/2005	12.0
Jardins	06/2005	02/2006	19.6
Ferreira de Araujo	02/2006	*	12.6
Domingos de Moraes	11/2012	*	30.0
Joel Jorge de Melo	09/2012	01/2013	13.3
Magalhães	09/2012	02/2013	13.3
Jesuino Maciel	06/2012	08/2012	13.6
Roque Petrella	06/2012	08/2012	13.2
Alexandre Dumas	05/2012	09/2012	13.2
Paulo Eiró	09/2012	01/2013	13.2

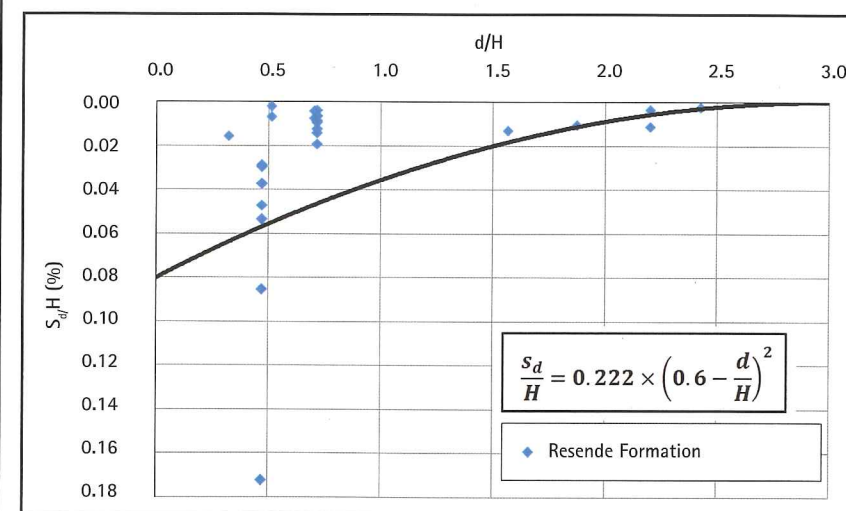
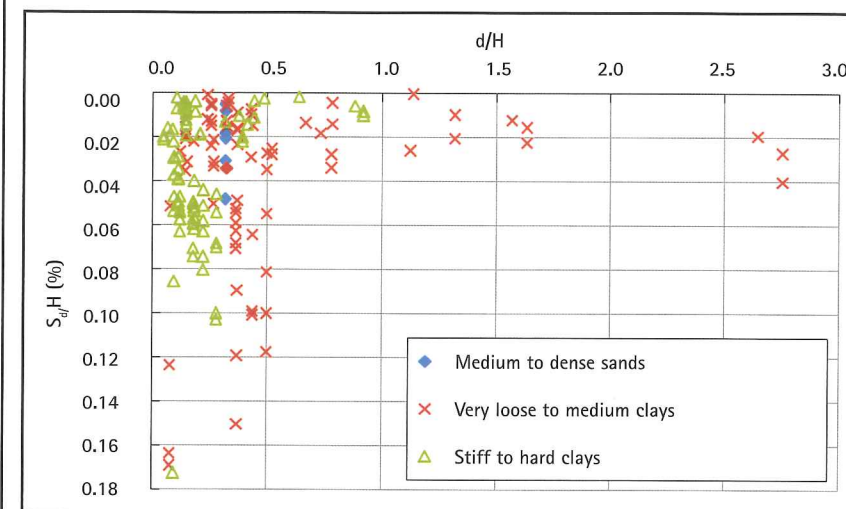
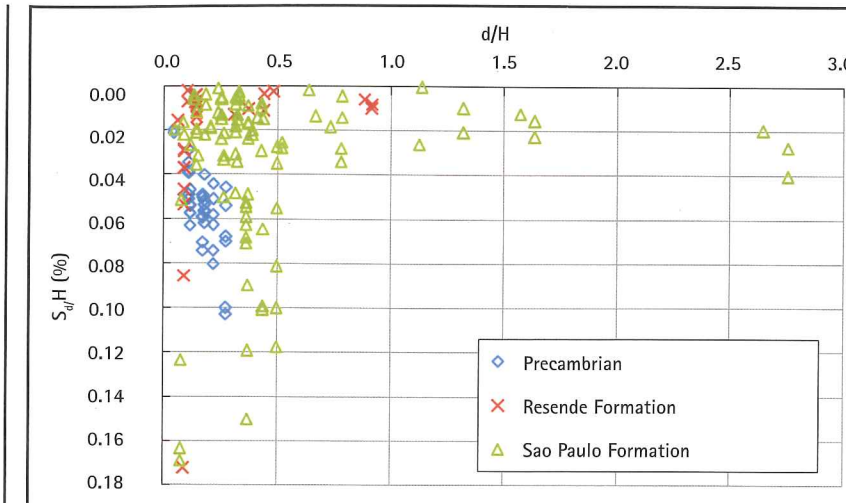
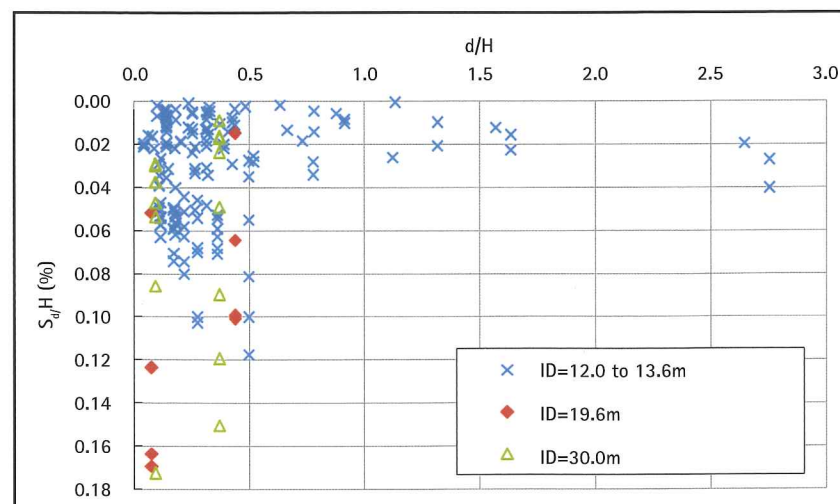
Surface Level [m]	Bottom of Excavation [m]	Total Height [m]	GWT Depth [m]	Shotcrete Thickness [cm]
796.6	762.3	34.2	8	25**
769.0	743.5	25.5	10	25**
729.0	696.0	33.3	5	20
797.8	745.0	52.8	9	70**
804.8	746.0	58.8	8	45**
768.0	734.0	34.0	8	40
741.0	717.0	24.0	4	30**
736.0	699.5	36.5	4	30**
758.0	723.5	34.5	10	30**
759.7	726.7	33.0	10	30**

* Reference not found.
 ** Average value.
 Source: Authors

Right, middle: Figure 8, Settlement data by granulometry and stiffness

Below: Figure 6, Settlement data collected

shafts were built. Precambrian is composed of granite and gneiss residual soils. Resende tertiary formation corresponds to a sequence of low sandy gray clay, and gray and yellow silty sand, generally little argillaceous. São Paulo tertiary formation occurs predominantly above 760m elevation, and is composed of two main litofacies. The first one is composed of rough sandstone, sometimes



conglomeratic and graded, the second one is composed of sandstone with average to rough grains, also graded, up to claystone and siltstone, with plane-parallel horizontal stratifications and great side persistence, Riccomini & Coimbra (1992).

Data analysis instrumentation

The data used in the analysis were collected from SACI: ('Monitoring System and Iterative Control of Instrumentation'),

Top: Figure 7, Settlement data by geology

Bottom: Figure 9, Equation of Resende Formation settlement upper limit

Kuwajima (2012). As the monitoring system results have been recorded online, the collection of data has been made easier.

The selection of shafts was made bearing in mind: representativeness and availability of data, the use of SCL support and circular shape of the shafts, Table 2 shows the characteristics of the selected shafts.

Settlements were measured by ground settlement pins. Analysed shafts had one or two ground pins per instrumentation axis; data from levelling pins installed in buildings were not used because of the interference of the building structure stiffness.

Figure 5 (see page 45) shows some parameters of interest for setting up the empirical method.

For the construction of the analysis graphs, two indicators were used: d/H defines the ratio of the distance from the shaft edge to the depth of the shaft and Sd/H defines the ratio of the settlement at a given distance from the shaft edge to the depth of the shaft.

Figure 6 (see page 46) shows the 161 measured settlements data, sorted by the different shaft internal diameters. Although it is possible to see the correlation of bigger settlements due to bigger internal diameter shafts, the collected data are not enough to analyse this parameter and further studies have to be carried.

Figure 7 shows the data classified by geology.

To classify the data by granulometry and stiffness (Figure 8) the Table 3 (see page 48) was considered.

RESULTS

For all the analysed shafts, the position of the ground water table initially changes between 4 to 10 m (Table 2) and all the shafts had a total water table dewatering (the GWT was lowered to the bottom of the excavation by deep pumps). As a result of that, the analysed settlements occur due to increase in the effective stress associated with the excavation and water table dewatering (settlements due to consolidation). The water table registered in Table 2 believed to be a usual hydraulic condition for the São Paulo soils; in shafts excavated without water table dewatering the results presented are therefore conservative.

The data presented in Figure 6 were subjected to statistical analyses which assumed that the shape of the settlements profile is a parabolic equation, New & Bowers (1994). The following equation is proposed for

predicting settlements associated with SCL shaft construction:

$$[1] \frac{s_d}{H} = \alpha \times \left(\beta - \frac{d}{H}\right)^2$$

Where S_d = settlement at a given distance from the shaft edge (m), H = depth of the shaft (m), α = dimensionless empirical constant, β = ratio of settlement width to shaft depth and d = distance from the shaft edge (m). Note that $\beta = W/H$, where w = settlement extension or width (Figure 5, page 45).

In order to minimise the influence of instrumentation errors it was considered that the settlement curves are the upper limits of 95 per cent of the data.

The equations of the curves were then determined to the Resende and São Paulo Formations, very soft to medium and stiff to hard clays. To Precambrian very loose to loose and medium to dense sands, was not possible to obtain the equations due to the small number of data. Furthermore the layers of the Resende and São Paulo Formations are repetitively interspersed, and in the São Paulo Formation, the sand is considerably argillaceous. It was considered that the geomechanical behavior of sandy-clays or clayey-sands is represented as clays.

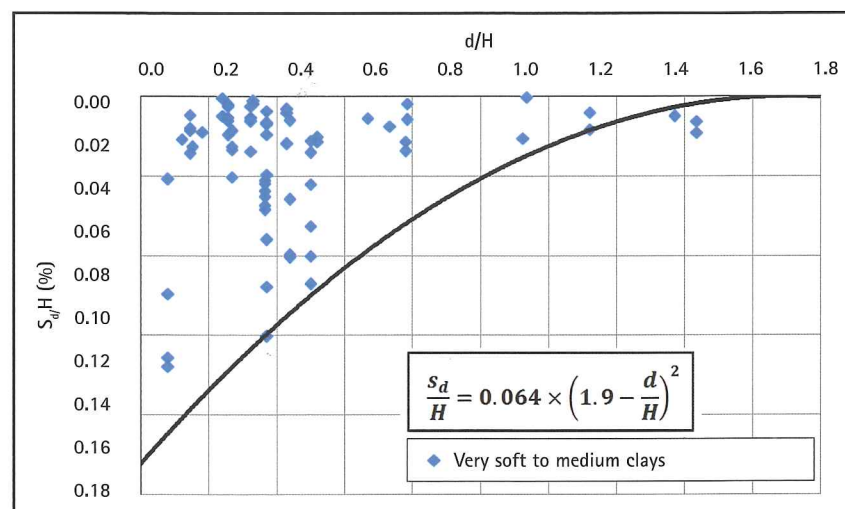
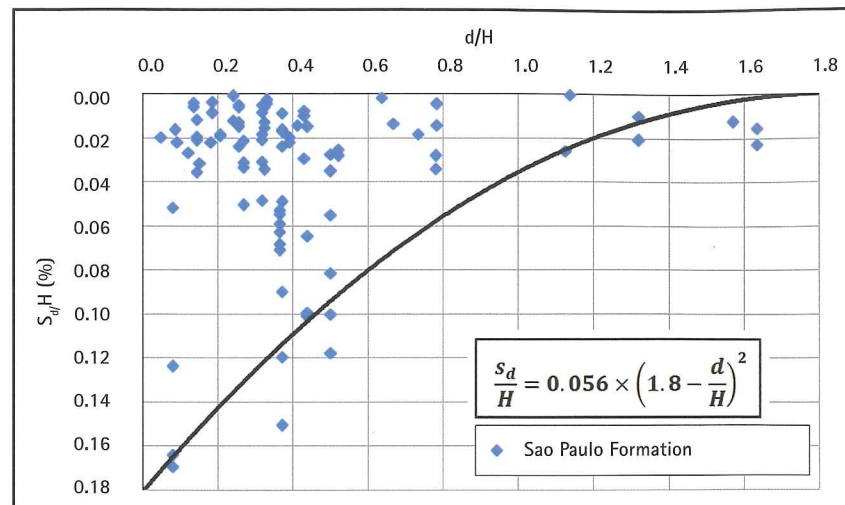
Figure 9 presents the equation upper limit of settlements for the Resende Formation instrumentation data. This and the next graphs show that the highest concentration of points occurs for low W/H values, due to the position of the ground settlement pins is typically close from the shaft edge (where the biggest settlements are expected to occur). Next the upper limit equation for settlements (Figure 10), was defined to the São Paulo Formation instrumentation data. Considering granulometry and stiffness, the data were sorted in very soft to medium and stiff to hard clays, both soils presented in the Resende and São Paulo Formations.

Figure 11 shows the resulting equation from application of the methodology for very soft to medium clays instrumentation data.

Figure 12 shows the resulting

Material	N_{SPT}	Classification
Sands (Granular Soils)	< 9	Very loose to loose
	≥ 9	Medium to Dense
Clays (Cohesive Soils)	< 11	Very soft to medium
	≥ 11	Stiff to hard

Source: Authors



Top: Figure 10, Equation of the upper limits of settlements considering Sao Paulo Formation data

Above: Figure 11, Equation of the upper limits of settlements, considering soft to medium clay data

equation for the stiff to hard clays instrumentation data. The obtained equations are below and charts in Figure 13.

$$[2] \text{ Resende Formation: } \frac{s_d}{H} = 0.222 \times \left(0.6 - \frac{d}{H}\right)^2$$

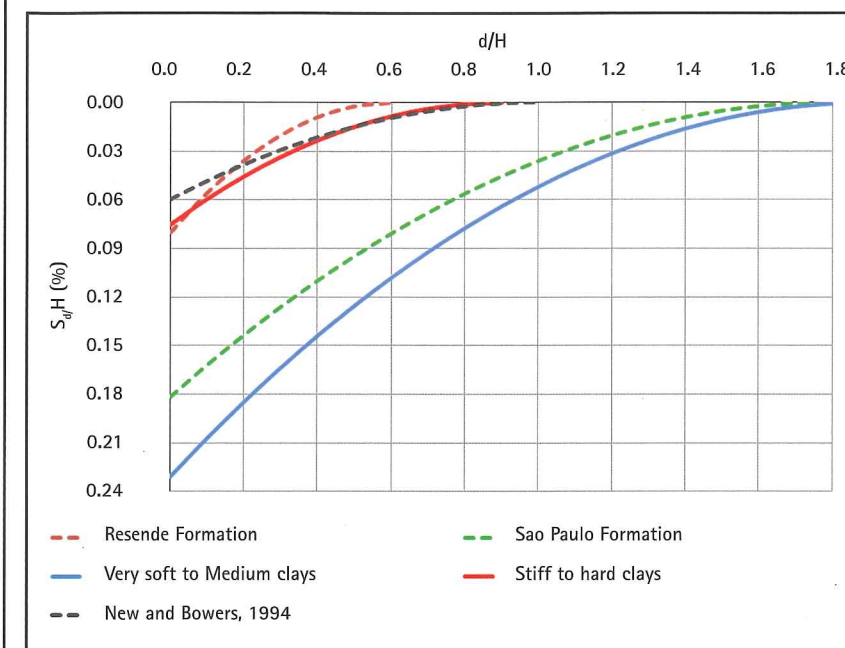
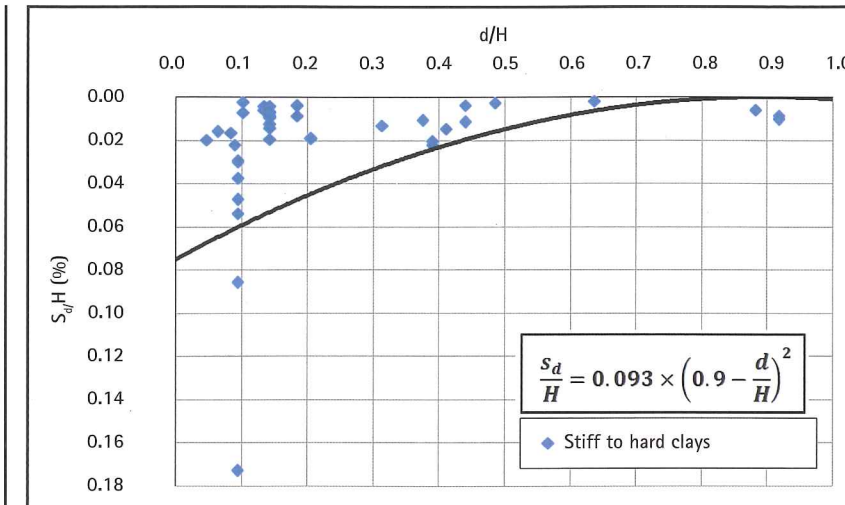
$$[3] \text{ São Paulo Formation: } \frac{s_d}{H} = 0.056 \times \left(1.8 - \frac{d}{H}\right)^2$$

$$[4] \text{ Very soft to medium clays: } \frac{s_d}{H} = 0.064 \times \left(1.9 - \frac{d}{H}\right)^2$$

$$[5] \text{ Stiff to hard clays: } \frac{s_d}{H} = 0.093 \times \left(0.9 - \frac{d}{H}\right)^2$$

Analysing the width of settlements profile we conclude it is smaller than two times the depth of the shaft, for very soft to medium clays, and one time, for stiff to hard clays. Comparing with Peck (1969), a classical method to estimate settlements due to open trenches excavations, the results are four times and two times, respectively. The differences result from the particularities of the excavation methods, previously discussed, and demonstrates that care should be taken when choosing the method for estimating settlements. For the maximum settlement it can be observed that 0.23 per cent of the depth of the shaft is an upper limit for the analysed data.

Figure 13 also shows the chart of New & Bowers (1994) Equation based on monitoring of a 26m deep, 11m diameter, and caisson driven shaft in London Clay at Heathrow. The chart is obtained using the Equation 1, and taken α as 0.06 per cent and β as 1.0. This suggests some similarities between London Clay and the stiff clay from São Paulo known locally as Taguá.



The curves obtained for geology, granulometry, and stiffness seem to create two groups. The Resende Formation and stiff and hard clays yielded similar results; and separately the results for the São Paulo Formation and very soft to medium clays were alike. This is due to the predominance of stiff and hard clays in the Resende Formation. While in the São Paulo Formation the predominant soils are very soft to medium clays. It is important to note that the differences between the São Paulo and Resende Formation settlements have a ratio of a 1/3.

CONCLUSION

Considering São Paulo geology it was demonstrated that settlements due to shafts excavation are almost three times greater in the São Paulo Formation when compared to the Resende Formation. The study of more than 150 settlements instrumentation data had led to obtain an empirical method of estimating settlements due to shafts excavations executed by sequential excavation and using SCL as support.

This method considers the axisymmetric condition, excavation/support installation by phases, water table dewatering and different geologies. Although simple and empirical, the method showed interesting results that may be used in similar cases for instrumentation design.

Top: Figure 12, Equation of the upper limit of settlements, considering stiff clays data

Above: Figure 13, Equations of the upper limits of settlements, considering geological units, granulometry and stiffness

The authors would like to thank the São Paulo Metropolitan Company - Metrô (CMSP)

Finally, a limitation of this method is that it does not consider shaft diameter as a parameter of the equations. As discussed, this is a limitation of the analysed data and needs to be investigated further. However, the proposed equations are appropriate for SCL shafts of 12-20m internal diameter. And for smaller diameters, the equations will tend to be conservative.

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HOT PROGRESS

Fire safety and evacuation are making further advances in metro systems. **Patrick Reynolds** reports

FATHI TARADA, managing director of tunnel and fire safety consultant Mosen, says the provision of combustion-resistant rolling stock, and that can be easily evacuated, is crucial in metros. He highlights the recently published EU standard EN 45545 to specify engines and carriages.

Tarada notes, though, that it will take time to shift all rolling stock over to higher standard fleets, which therefore presents some ongoing risk – despite underground railway tunnels and stations being, he says – “without any doubt, generally safe.”

Karl Fridolf, a fire safety researcher with SP Technical Research Institute of Sweden, says the self-rescue principle “is essential” when discussing evacuation of underground transportation systems.

The key to the metro design would then be to enable passengers, in an emergency, to “evacuate to a safe place” with the technical installations of the subway system providing them sufficient help to do so. No waiting for the arrival of emergency services personnel; instead, the design – the designer – must show how successful evacuation can be achieved under different scenarios.

Fridolf says there are many different technical installations related to life safety, and their choice and use differs between projects. Systems can include emergency exits (including those in tunnels), exit signage, fire alarms, smoke extraction systems, and sprinklers.

WATER

Armin Feltmann, sales engineer on tunnel systems with water-based fire safety systems manufacturer Fogtec, says fire loads have changed in recent years which consequently demands improved fire safety measures in metro stations.

Feltmann says there are, basically, two protection concepts in approaching fire safety in metros and these focus on the rolling stock and the infrastructure, respectively.

With respect to infrastructure, fixed fire safety system (FFFS) can protect station structures. The FFFS is based on high pressure watermist technology, with nozzles and pipework installed above the railtracks. The watermist is designed to minimise the effects of the fire, suppressing it through fast activation

(by using clean water, rapid release is possible without danger or delay), reducing heat radiation, and cooling the gases and smoke which reduces their volume, thereby also cutting down the load on the ventilation system.

The combination of benefits of the suppression system, which chokes off the fire and helps contain the area being affected, helps passengers evacuate and fire fighters gain critical access – nearer to the source of the incident, and sooner. The containment also minimises the damage to the station infrastructure, and therefore downtime for repairs – “even in the case of severe fires,” says Feltmann.

Fogtec’s technology is also a key component of the FFFS system that helps to manage fire safety in one of the world’s longest underground rail links – the Channel Tunnel. Like on that giant transport scheme, watermist systems can be retro-fitted in urban transit networks like underground metros – “especially when there is only little space available,” says

Below: Testing metro tunnel evacuation
PHOTO: KARL FRIDOLF



Feltmann.

Although retro-fitting in any engineering context may present its own challenges, the possibility to introduce the watermist system, for example, could offer potential cost savings compared to other approaches, he suggests. Key factors in the possibility to do so come from infrastructure protection and less ventilation capacity being needed, says Feltmann.

Recent implementation of the watermist system in Budapest saw metro operator BKV retro-fit the system into nine stations of its M2 line. BKV introduced the system from the outset in the design of 10 stations on the M4 line. In addition to the main platform areas in stations, key sections to be protected by watermist systems include escalators, cable tunnels, and the control and inspection room.

SYSTEMS

Draeger takes a broad, integrated systems-based approach to safety management in tunnelling projects, including provision for dangers of toxic gases and fire safety – during both construction and operational phases of an infrastructure scheme, such as a metro.

During the construction phase, a variety of equipment can be in place to help safety, such as refuge chambers, medical equipment, fire trucks and ambulance trains. For this phase, and operations, there can be monitors (including access to tunnels) and various detectors (gas, smoke, infrared).

Refuge chambers are being adapted from the mining sector to play an increasing role in many types of tunnelling

Fire Safety Research

Recent research in fire safety in tunnels has included Sweden’s “METRO” project for subways, and Germany’s “Safety of Life in Tunnels II (SOLIT-2)” – which focused on roads though took information from the Channel Tunnel. Both research projects completed in 2012.

Prof Haukur Ingason, a senior fire safety researcher with SP Technical Research Institute of Sweden, says key outcomes of METRO included heightened awareness of high heat release rates and arson risk.

While there hasn’t been further research so far, SP has sought that the follow up should consider risks around terrorism, and possible coordinated attacks, such as: terrorist use of accelerants and/or small explosives; design weakness of present subway systems; improved evacuation strategies; and, enhancing strategies and equipment for first responders.

While focused on roads, one of the interesting conclusions of SOLIT-2 was that water-mist systems might allow for a higher safety level and savings” in other, conventional, equipment also used in fire safety solutions. The report outlines ways for fire tests to help in layout design for FFFS on a project.

projects, and would help in a variety of risk scenarios. Manufacturer MineARC Systems has seen its refuge chambers used as part of safety solutions on metro projects in Kuala Lumpur and Doha. Other manufacturers include Strata Worldwide. MineARC notes it is possible to incorporate refuge chambers into transportable standby safety systems during the operational life of tunnel projects.

TESTING, TESTING

Use of the assets needs to be coordinated with effective operational rules – eg a train on fire should not stop but continue, at a pre-determined control speed, to the closest station to evacuate its passengers.

But when testing people in a smoke-filled space, as could be experienced by passengers in a tunnel or possibly having been delivered to a station platform, the emergency criteria must take-in further aspects, including, and not least: safety is in the eye of the beholder.

If people are thrown into a situation, what might they think they see? The mind tries to make sense of the world through patterns, and in split seconds what might be constructed in the mind, and believed, may well be acted upon.

Fridolf tells of a test where some people moved sharply away from an exit fitted out, from the design concept, to have green and white halogen spotlights. Why? In debriefings, the people – only aware they were in a smoke-filled tunnel – said they thought the lights were on the front of a train. Not a door leading to safety.

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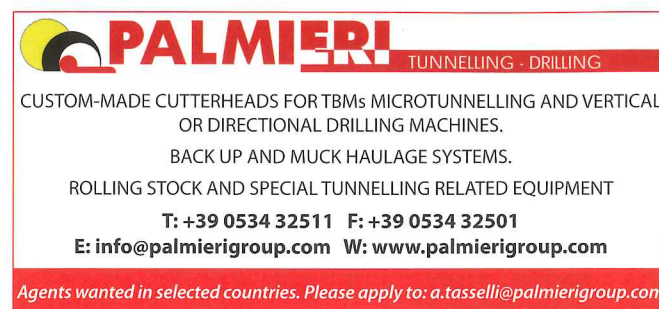
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Post-2015 Framework for disaster risk reduction

14-18 March 2015
 Sendai, Japan
 UNISDR is facilitating the process of developing a post-2015 framework for disaster risk reduction. This process will culminate at the 3rd United Nations World Conference on DRR
unisdr.org/we/coordinate/hfa-post2015

BTS Young Members Conference

27 March 2015
 London, UK
 The BTSYM Conference 2015 will be held at Pinston Masons, London on Friday 27 March. Places are available to those aged 35 or under. Online booking is now open.
<http://tinyurl.com/pftjf2d>

ISRM Congress 2015

10-13 May 2015
 Montreal, Canada
 Held in conjunction with the CIM Convention for 2015, the International Symposium on Rock Mechanics is an international conference every four years.
www.ISRM2015.com

World Tunnel Congress 2015

22-28 May 2015
 Dubrovnik, Croatia
 WTC 2015 heads to the Dalmatian Coast as the annual event returns to Europe. Further details are available on the event website.
www.wtc15.com

RETC

7-10 June 2015
 New Orleans, Louisiana
 The Underground Construction Association's biennial conferece will this year be held in New Orleans.
www.smenet.org

49th US Rock Mechanics / Geomechanics Symposium

28 June-1 July 2015
 San Francisco, California
 The 2015 program will focus on new and exciting advances in rock mechanics and geomechanics and encompasses all aspects of rock mechanics, rock engineering, and geomechanics.
www.armasyposium.org/

Eurock 2015 & 64th Geomechanics Colloquium

7-10 October 2015
 Salzburg, Austria
 The ISRM Regional Symposium EUROCK 2015 Future Development of Rock Mechanics, is to be held in conjunction with the 64th Geomechanics Colloquium
www.eurock2015.com

25th World Road Congress

2-6 November 2015
 Seoul, South Korea
 The World Road Congress has been held every four years for more than 100 years. Since the first meeting in Paris in 1908, it has toured the member countries of the non-government organization, Permanent International Association of Road Congresses (PIARC).
www.aiprseoul2015.org

Stuva Conference

1-3 December 2015
 Dortmund, Germany
 Held every two years, this conference sees 1,500 participants and visitors from about 20 countries. It is numbered among the world's leading get-togethers for underground construction experts. In 2015 the chosen venue for this premier event is Dortmund.
www.stuva-conference.com

2016

World Tunnel Congress 2016

22-28 April 2016
 San Francisco, USA
 World Tunnel Congress 2016 returns to North America. Further details are to be confirmed. Please note the earlier than usual date for the event this year.
www.wtc2016.us

Underground Construction Prague 2016

23-25 May 2016
 Prague, Czech Republic
 Past conferences confirmed that the Prague conference, thanks to its scientific programme, venue and social programme found a firm position among similar European conferences. The 2016 event will also be enhanced by the Third Eastern European Tunnelling Conference (EETC 2016).
www.ucprague.com

British Tunnelling Society

The BTS has a membership of almost 700 individual and 60 corporate members. It is one of the most vibrant gatherings of professional tunnellers in the world and traces its history back to its founding in 1971. Regular BTS monthly meetings are hosted at the Institution of Civil Engineers in London from 5.30pm every third Thursday of the month. In recent years, the BTS Young Members have also begun hosting a programme of evening lectures.

Harding Prize

16 April 2015
 The annual Harding Prize competition is named in honour of Sir Harold Harding, the founder Chairman of the BTS and is open to young engineers aged 33 or under at the end of 2013. Entrants must submit an original paper relating to any aspect of tunnelling they consider of interest to the industry. The winner will be chosen by the BTS Committee. Speaker: Harding Prize finalists

BTS Annual Dinner

8 May 2015
 The 27th BTS Annual Dinner will be held at the now tradition Brewery venue on Chiswell Street in London, 7.00pm-1.00am. Booking is now open but places are going fast. See the BTS website for more details.

East Side Access project

21 May 2015
 Speaker: Andy Tompson

Tunnelling in the Lambeth Group: how can we stop it going wrong?

18 June 2015
 Speaker: Jackie Skipper

Innovation and technology in segmental lining design

17 September 2015
 Speaker: Anthony Harding

Waterview Connection project in Auckland, New Zealand

15 October 2015
 Speaker: Chris Ashton

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

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