

INTERNATIONAL EDITION

October 2014

# Tunnels

AND TUNNELLING

*China's 120km  
Liaoning project aims  
to solve Shenyang's  
persistent droughts*

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## OLD DOGS TEACH NEW TRICKS

**B**Y NOW it's an autumn tradition in the UK. The leaves are turning, the daily commute has the added pleasure of the flu virus, and a study has warned that we face a critical shortage of engineers.

Last year the focus was on competing for the best and brightest. We had to be sure to encourage the sharpest minds to embark upon an engineering career (underground) and to educate them in the skills and training needed to enter the industry. The British Tunnelling Society led the way in proposing at WTC that the international community form young members groups, part of the purpose of which would be to encourage new engineers into the industry.

The year before, the European Union launched the 'Science - It's a girl thing' as study groups identified an alarming lack of women taking up engineering and the sciences in higher education. This was quickly slammed as offensive and banal. The efforts of the industry, however, were more dignified. Again we highlighted the work of the younger engineers in schools, and the emergence of the Women in Tunnelling group.

This year, the warning is that an ageing engineering workforce may be a threat to the ability of various sectors to meet demand. And according to industry body Engineering UK, Britain alone needs to train 87,000 engineering graduates a year until 2020 to replace those retiring.

Every problem contains within itself the seeds of its own solution, and the industry's wealth of engineering experience has certainly been put to use. In 2011/12, the UK's first MSc in Tunnelling and Underground Space was launched at the University of Warwick. From nine full time students then, to a total of 23 (including some part timers) this year, the BTS and Warwick's director of tunnelling and underground space Benoit Jones can be proud of what they have achieved.

The BTS was instrumental in setting up the course, and play a very active role in guiding it to this day, with two

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Alex Conacher  
Deputy Editor



steering board meetings per year. Some 20 per cent of lectures are given by a guest, invariably a BTS member. And in addition, each module has a 'champion' who is responsible for looking into the syllabus, and keeping it relevant and of a high quality.

Due to expressed interest, and the concentration of tunnellers in London, there is even talk of evening classes being considered for future students. All this is another string to the bow, and can bring fresh blood into the industry.

There is change at T&T too. After three and half years of dedicated service, Jim Moore is leaving T&T to seek new challenges in a new industry. It was World Tunnelling that launched Jim's career in tunnelling media, but he truly came into his own as head of sales at Tunnels & Tunnelling. During his tenure, Jim oversaw a very successful period, raising the bar with some record breaking performances.

We can't thank him enough. Jim may not look back on the industry again, but his friends in the game will always remember him and look out for him. He was just that kind of guy.

Good luck from all at T&T!

### This month...

#### 20 YEARS AGO

In excess of 85 categories of safety violations have been discovered by inspection teams from the California Occupational Safety and Health Administration (CalOSHA) following a safety audit of Los Angeles Metro Rail construction projects. Fines from the violations, 33 of which were classed as serious, will total approximately USD 175,000. Underground violations included substandard electrical equipment, broken light fixtures, and evidence of smoking in areas being monitored for explosive gas. A spokesman for the Los Angeles County MTA responded that "the overall safety record is better than the national average". However, the MTA wants contractors to improve and will require them to file regular progress reports. *Tunnels and Tunnelling, October 1994, p.7*

#### 40 YEARS AGO

Ten years after the patent was taken out for the bentonite tunnelling process, the first commercial contract using this method of driving a tunnel in unstable ground has been awarded to Edmund Nuttall by the Warrington New Town Development Corporation in the UK. There has been much interest expressed in this form of tunnelling, much of it from Continental Europe. In Holland for example, the ground is so poor that there have been virtually no bored tunnels to date. At the moment, several interested parties are watching this first commercial contract with interest. *Tunnels and Tunnelling, September/October 1974, p.9*

**Cover**  
At over 120km in length, China's massive Liaoning project aims to solve Shenyang's persistent droughts



**Next issue**  
The next issue of Tunnels and Tunnelling will publish site reports from the Warsaw Metro's second line in Poland, and large slurry works for a Gdansk road project, also in Poland. This issue will also carry the final runner-up from this year's BTS Harding Prize.



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GRANDS PROJETS

## SECOND GOTTHARD ROAD TUNNEL GIVEN THE GO-AHEAD

**SWITZERLAND** — Swiss Parliament has paved the way for a second road tunnel through the Gotthard in central Switzerland. Voters are likely to have the final say on the issue in a nationwide ballot.

Following a debate that took place last month, the House of Representatives agreed to drill an additional shaft and renovate the existing road tunnel after more than 30 years in operation. The Senate had approved the bill in March.

The government has decided to upgrade the second tunnel into a full

road tunnel in order to allow for the necessary reconstruction of the first road tunnel. Once the works on the first tunnel are finished, the Swiss government plans to operate one single lane in each tunnel (northbound traffic in the newly constructed tunnel, southbound traffic in the renovated one) in order to maintain the current tunnel overall capacity, in compliance with the Swiss constitutional norm that forbids a further growth of the traffic capacity across the Alps.

An alternative upgrade proposal that was dismissed saw the tunnel closed for

the renovation and traffic diverted over the mountain pass. Another proposed to load the vehicles onto trains with a new terminal, a third would close the tunnel for several months every year over time range of a decade.

Further use of both tunnels is subject to a popular referendum that will probably be held in 2015. The actual upgrade mining of the second road tunnel would last from 2020 to 2027 at a cost of CHF 2.7bn (USD 2.9bn) for the whole project including the following reconstruction of the first tunnel.

### London Underground launches new night tube service

**GREAT BRITAIN** — The mayor and London Underground (LU) announced last month that 24-hour 'night tube' services at weekends will begin operation from the early hours of 12 September 2015, reducing night-time journeys by an average of 20 minutes and some by more than an hour.

The announcement comes as independent research into the economic benefits of the night tube found that the new service will boost jobs and help maintain London's status as a vibrant and exciting place to live, work and visit. London will join other top cities, including New York and Berlin, which also provide underground services through the night.

Boris Johnson, mayor of London, said: "London is a bustling, 24-hour global city and by this time next year we'll have a 24-hour Tube service to match. Running trains all through the night was once thought impossible, but with the huge investment we've put in and upgrades that have been delivered we stand ready to take the Tube to the next level. As well as creating vital new jobs and giving a huge boost to our

economy, the Night Tube will help millions of people to get around our city more easily and quickly. The evolution of the Night Tube will without doubt make London an even better place to live, work, visit and invest."

Mike Brown MVO, the managing director of London Underground, added: "We are now less than a year away from the first ever 24-hour services operating on London Underground. Already over half a million Londoners use the Tube after 10pm on Fridays and Saturdays, and the introduction of the Night Tube, which will cut journey times and open up new possibilities across the night time economy, is a historic step in our modernisation of the Underground.

"The new service will boost jobs and will benefit the economy by hundreds of millions of pounds. We will also now be exploring any sponsorship opportunities that could make this transformative service even more cost-effective."

### India announces underground sewer

**INDIA** — India for engineering and designing the installation of a new underground sewer network.

The works, as part of the

National Ganga River Basin Project, will include building the sewer network stretching to 198km in length.

Proposals are due by 14 October 2014.

Details regarding this project can be viewed in the listing on dg Market Tenders Worldwide.

### Terratec delivers TBM for Istanbul metro

**ISTANBUL** — Terratec has announced a new TBM delivery for Istanbul Metro in Turkey in late August following the successful performance of the workshop testing. The TBM is a 6.56m EPB Shield designed to excavate Istanbul's mixed geology.

The official ceremony was held on Terratec's facilities in the presence of representatives from the client, a joint venture among the parties of Gülermak, Kolin and Kalyon (GKKJV).

The TBM will be transported to Turkey and commence boring at site before end of the year.

"We are pleased that the Terratec TBM was ready as promised in record breaking time and look forward to great performance when it arrives on site" said Emre ÇELİK, the JV's vice project manager.

The JV targets to build a leading-edge rapid transit line on top of the existing Istanbul Metro system between Mecidiyekoy and Mahmutbey in the east and west respectively of the European side of the Eurasian megalopolis. The new line will be 17.5km in length and consist of 15 stations, the journey time between both locations will take only 26 minutes. It is expected to be in service by 2017.

### London 'ghost' tunnels to be sold off

**GREAT BRITAIN** — "Ghost" London Underground stations are set to become a network of tourist attractions, hotels, shops and museums, it was revealed last month.

Transport for London (TfL) is preparing to invite companies to bid to transform London's abandoned underground stations and horse tunnels beneath the capital's streets.

TfL is believed to be in talks to decide whether it invites consultancies and construction firms to bid for just one site to kick-start the project, or a collection of the spaces hidden below London.

The public body owns 750 of the tunnels and is looking to transform the portfolio of assets.

**London road tunnels upgrade awarded**

**GREAT BRITAIN** — Transport for London (TfL) has appointed Indra to modernise the technology for the control and operation of the 12 road tunnels in London, some of which are more than 100 years old, as well as 90km of approach roads, the public authority stated last month.

The new contract covers the design, installation, commissioning and maintenance of a new integrated system to support the London Streets Tunnels Operations Control Centre (LSTOC).

Currently, LSTOC uses multiple control systems to operate and control safety and traffic control systems, communicate with road users, emergency and maintenance services people and to manage safety and minimise disruption.

The new system is

expected to improve how real-time information is presented to and used by LSTOC and the London Streets Traffic Control Centre (LSTCC), who work with other incident responders such as the emergency services to deal with traffic incidents.

These improvements will also allow for real-time information about incidents in the tunnels to be obtained, allowing TfL to minimise the knock-on effects these can cause across London's streets.

Dana Skelley, director of roads at TfL, said: "This new system will help to improve the safety and efficiency of all the tunnels that we manage in London.

This is part of our wider programme of investing in tunnel improvements and roads as a whole.

We are committed to keeping London moving and this is just another step to making sure that people can get around quickly and safely."

London's roads account for 80 per cent of all journeys and 90 per cent of all goods moved in the capital.

TfL stated that the upgrade is expected to allow for more efficient control of day-to-day running of London's road tunnels and enable emergency situations to be dealt with more promptly.

**NRT consortium reaches contractual close on PPP**

**AUSTRALIA** — The Northwest Rapid Transit (NRT) consortium, which consists of John Holland, Leighton Contractors, MTR Corporation, UGL Rail Services and Plenary Group, has reached contractual close on a Public Private Partnership (PPP) with the New South Wales Government to deliver the AUD 3.7bn (USD 3.2bn) Operations, Trains and Systems (OTS) package for

the North West Rail Link (NWRL) in Sydney.

The NRT consortium will procure rolling stock and design, build, finance, and then operate the NWRL's 36km rapid transit train service for a 15-year period. The net present value to the Leighton Group is AUD 2bn (USD 1.75bn).

Under the PPP arrangement a four-way joint venture between MTR Corporation, John Holland, Leighton Contractors and UGL Rail Services will deliver the five-year construction phase.

Glenn Palin, managing director, John Holland, said: "NRT is committed to a successful partnership with the NSW Government. To that end, we will ensure construction, fit out and systems seamlessly meet operational needs so that commuters in the North West benefit from a safe, efficient rail service."

David Jurd, managing director, Leighton Contractors, said: "The NWRL will improve travel times, accessibility and amenity for commuters, paving the way for sustainable growth in Sydney's North West and delivering wider benefits to the state's economy."

The NWRL is the first stage of Sydney Rapid Transit, Sydney's new railway network and is scheduled to commence services in the first half of 2019.

**Tyne Tunnel staff celebrate long service**

**GREAT BRITAIN** — Three workers at Tyne Tunnel operator TT2 Limited are celebrating a combined 90 years service.

Ron Henderson has reached his 30th anniversary, with senior tunnels officer Simon Maughan and shift controller Anthony Harbison reaching the milestone in October. They will next year be joined by Allan Carty, Malcolm Carr and Karl Walters.

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## DESIGNER APPOINTED FOR COLLIDER TUNNEL DESIGN

**EUROPE** — The European Organisation for Nuclear Research (CERN) has appointed engineering consultancy Arup to undertake conceptual design studies for both the tunnel engineering and geotechnical aspects in the scope of the Future Circular Collider (FCC) study.

As a response to the recommendation made in the European Strategy for Particle Physics in 2013, CERN director general, Dr Rolf Heuer, announced the launch of a study in a global context, with an emphasis on next-generation proton-proton and electron-positron high-energy frontier particle accelerators.

Arup has been working closely with CERN and project partners

Géotechnique Appliquée Dériaz S.A. (GADZ) and Amberg Engineering AG, to deliver the first phase of the conceptual design study.

A key element of this stage has been the development of an early stage Building Information Modelling (BIM) tool to inform performance, risk and cost optimized options for a 100km long, circular particle-accelerator tunnel. Arup has developed a dynamic Web-based GIS application, which integrates

numerous existing geological data sources, incorporating the geological, tunnelling and particle collider system constraints in a user-friendly digital environment.

Matt Sykes, project director, Arup, said: "Using BIM this early on in the design process is invaluable. It allows us to make critical decisions using data that can be easily visualised, enabling the team to make decisions with a clear overview of the multiple, highly complex components of this ground breaking project. We're delighted to be working with such a far-sighted client and strong project team to help CERN achieve its objective to break new boundaries in particle physics research."

John Osborne, civil engineer, CERN, added: "Several layouts for this new machine are under consideration, with the tunnel circumference ranging from 80 to 100km. This tool being developed by Arup, will be crucial in the decision making process, to help decide which layout is most feasible."

The new accelerator tunnel would be nearly four times the size of the present Large Hadron Collider (LHC).

## GREEN LIGHT GIVEN FOR LONDON'S SUPER SEWER

**GREAT BRITAIN** — Thames Water has today been given the go-ahead to start building London's 'super sewer', which will tackle the sewage pollution in to the tidal River Thames.

The 25km tunnel will run underground from Acton storm tanks in West London, and travel roughly the line underneath the river to Abbey Mills Pumping Station in East London, where it will connect to the Lee Tunnel.

The sewage collected from the 34 most polluting discharge points along the tidal river in Central London, will then be taken via the Lee Tunnel to Beckton sewage works for treatment.

Last year, 55Mt of sewage polluted the tidal River Thames, far higher than the average 39Mt that discharges in a typical year. This was due to the exceptionally wet weather, which caused the combined sewerage system that London has, collecting rain water and sewerage water from drains, to fill up and pour into the river even more than normal.

With the weather of 2014 already proving to be wetter than a typical year, the amount of sewage that is going into the river is likely to once again be above average.

"If the tunnel had been in operation last year, it would have captured 97 per cent of the sewage that poured in to London's river," said Andy Mitchell, chief executive of Thames Tideway Tunnel. "Hardly a week goes by when

untreated sewage isn't pouring in to London's river and we are pleased that we can now start to tackle this archaic problem.

"This is a huge project but it's a huge problem, and we can now get on with tackling it. It's no easy task, but we're confident that we can deliver this project and still achieve our aim of minimising the impact on our customer bills."

The Thames Tideway Tunnel will take seven years to build, and main construction can now start in 2016 as planned.

The project has been given a Development Consent Order (DCO), by the Government, to be built as proposed using 24 construction sites across London.

It will involve using six tunnel boring machines from five drive sites and will directly create more than 4,000 jobs.

Mitchell added: "This DCO means we can improve London's river for the benefit of Britain. We appreciate the impact our construction work will have on some communities near our sites, but we will continue to work with them to keep disruption to a minimum."

The Thames Tideway Tunnel will be financed and delivered by an independent specialist company, separate to Thames Water and with its own licence from Ofwat.

Interested investors are currently preparing bids, with the successful bidder expected to be announced next summer.

### Femern announces pre-qualified firms

**DENMARK** — Femern A/S announced the group of firms and consortia that are pre-qualified for the contracts for the Fehmarnbelt tunnel's electrical and mechanical installations as well as the establishment of the sub-station, which will supply the tunnel and electric trains with power.

For the contract for the electrical and mechanical installations, four consortia comprising companies from Denmark, Austria, UK, Sweden, Spain, Italy, France and Germany have been pre-qualified.

Three consortia comprising companies from Denmark, France and Poland have been pre-qualified for

the sub-station contract.

I'm delighted that we will soon be able to put these two major contracts out to tender.

They concern, in part, all the intelligent systems that have to be installed in the tunnel tubes to ensure that traffic flow is safe and efficient and, in part, the entire power supply for the fixed link in the form of a sub-station," says Kim Smedegaard Andersen, Femern A/S Contract Director.

Femern A/S has chosen to gather the electrical and mechanical installations into one large contract. The contract, which comprises a large number of different elements, is worth several hundred million euros.

The contract concerns the ventilation of the tunnel

and in buildings, emergency doors, fire suppression systems, drainage, cabling and pipework, elevators, transformers, lighting, monitoring and control systems as well as communication systems in the tunnel.

"On smaller projects, these tasks would typically have been split into separate contracts, but we have chosen to combine them because we want to have a completely integrated solution where all the parts fit together seamlessly," says Kim Smedegaard Andersen. "In this way, we are assured of the best solution for the Fehmarnbelt tunnel."

The second contract, which can now be put out for tender, comprises the establishment of a new

large sub-station east of Rødbyhavn.

The sub-station will supply power for train operations and the electrical installations in the tunnel. The trains will require significant power, which is why the sub-station will be large enough to supply a major provincial town of 10,000 households.

Work on the other railway installations such as track, catenary system and signalling will begin when the construction of the tunnel has been completed. Consequently, the first bids are expected approximately two years from now.

As regards the tender procedures, the pre-qualified companies will now prepare their technical bids for the contracts in line with the same tender model as for the four major tunnel contracts. Femern A/S expects to receive the final bids at the end of 2015, while contracts are expected to be signed in 2016.

### Femern announces pre-qualified firms

**SWITZERLAND** — Voters in canton Geneva have turned down plans to build a new 1.5km-long road tunnel under the lake close to the city's famous Jet d'Eau fountain.

Last week, 63 per cent of voters turned down the initiative to construct a tunnel at the far western end of the lake, local press reported.

The rightwing Swiss People's Party initiative and the Touring Club of Switzerland (TCS) motoring association, argued that the new road tunnel under the lake was needed to relieve the heavily congested city centre and the Mont Blanc Bridge.

Other political parties and a number of environmental and local community groups had rejected the initiative, calling it too expensive and environmentally unfriendly, local press stated.

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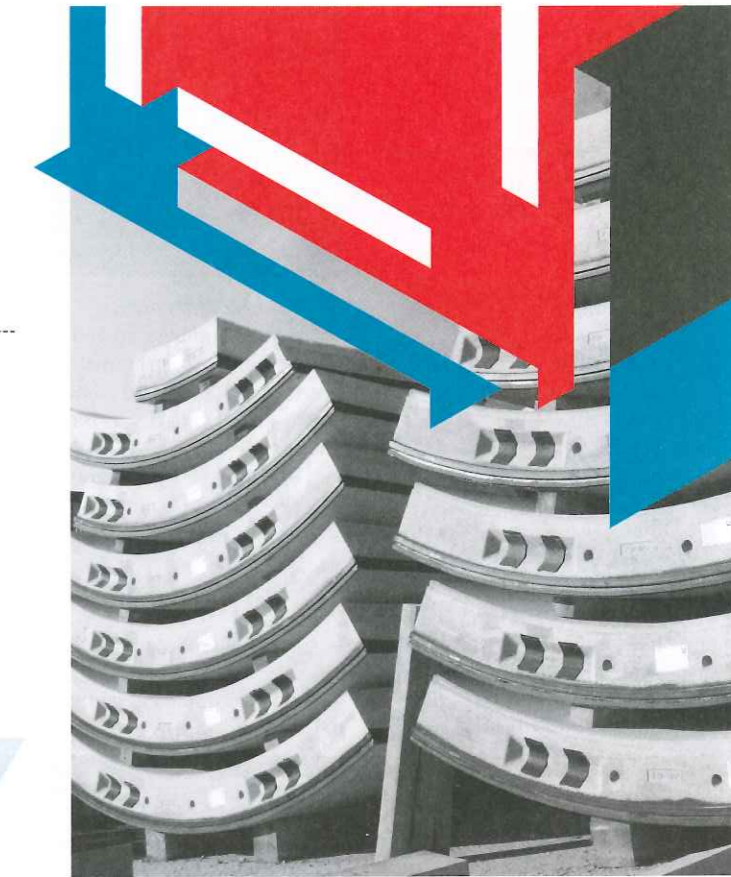
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Typical installation of the RST Profile Monitoring System for Tunnel Concrete Segments with an RST flexDAQ Datalogger System.



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**London's Bank station box fit-out awarded**

**GREAT BRITAIN** — Transport for London (TfL) has awarded the contract to fit out the brand new Waterloo & City line station entrance 'box' at Bank to construction specialists Hochtief UK Limited. The contract will provide a new step free entrance at the station giving passengers direct access to the Waterloo and City Line from Walbrook Square.

The 'box', which is being built by Sir Robert McAlpine while it is working on media firm Bloomberg's new European headquarters, is an

underground structure that will enable the subsequent installation of four new escalators, two new lifts and a new ticket hall.

To achieve planning consent Bloomberg agreed to work in partnership with London Underground to help increase the capacity at Bank Station.

Bloomberg's contractors will hand over the box to London Underground next summer, with the final fit-out scheduled to be completed by the end of 2017.

David Waboso, London Underground's Director of Capital Programmes, said: "The award of this contract

is an important step on our journey to deliver a bigger and better Bank station that can meet the challenge of increasing demand and help to provide quicker and easier journeys for customers. The step-free Waterloo & City line entrance and ticket hall, with new escalators and lifts, form a key part of our upgrade plans for Bank, one of London's busiest stations."

The contract is part of a GBP 57M (USD 92.9) major redevelopment at the Bank/Monument interchange. Bank station currently serves 98 million passengers per year and is one of London's busiest Tube stations.

**Scottish water contract awarded**

**GREAT BRITAIN** — Costain and Vinci Construction have been awarded a GBP 86M (USD 138M) contract by Scottish Water to construct the Shieldhall Tunnel in Glasgow. Costain announced yesterday.

The Shieldhall Tunnel will be Scotland's largest waste water tunnel, 4.7m in diameter and 3.1 miles long, and will form part of the biggest upgrade of Glasgow's waste water network in more than a century.

The tunnel will run between Queen's Park and the Craigton industrial estate, and will resolve water quality and reduce flooding issues at key locations in the area served by the Shieldhall Waste Water Treatment Works.

Work will start in October 2014 and completion is anticipated in early 2018.

In terms of the reduction of time costs, as well as from a humanitarian perspective."

**Bouygues wins HK Metro work**

**HONG KONG** — Through its subsidiaries Dragages Hong Kong and Bouygues Travaux Publics, Bouygues Construction has won a contract worth HKD 5.2bn (USD 620M) from MTR Corporation for the construction of 2x2 tunnels that will form part of a 6km extension of the Shatin to Central Link. These tunnels are among the major infrastructure projects currently under way in the city, connecting tourist sites and the financial district.

The two eastern tunnels, each approximately 540m long, will run from the south ventilation building and the new Exhibition station on the Shatin to Central Link. The two western tunnels, each 450m long, will be bored between the Fenwick Pier emergency exit and the existing Admiralty station.

**BREAKTHROUGH ON DEEP ROCK TUNNEL CONNECTOR**

**USA** — A 20.2ft (6.2m) diameter Robbins main beam TBM broke through in July the at the Indianapolis Deep Rock Tunnel Connector (DRTC) project. The machine set three world records in the process.

The project was put in place to reduce the amount of raw sewage overflows in the city's neighborhoods and clean up tributaries along the White River. Tim Shatters, construction supervisor of Citizens

Energy Group said: "There were a couple of different ways that we approached solving this issue and the one we chose was the deep rock tunnel because it would cause less disturbance for the people of Indianapolis, and afforded us the ability to upsize to a 5.5m diameter tunnel. We could store flows rather than convey them and upgrade the treatment facilities."

The Robbins main beam TBM, owned by Shea/Kiewit (SK) JV, was refurbished and redesigned for the job. Originally built in 1980, the TBM has previously been used on at least five other hard rock tunnels including New York City's Second Avenue Subway. The additions for the DRTC included new 19in (483mm) disc cutters, variable frequency drive (VFD) motors, a back-loading cutterhead, and a rescue chamber. The machine cut a 12.2km tunnel through limestone and dolomite 76m below the city. A Robbins continuous conveyor system that included a horizontal and vertical conveyor was used for muck removal.

Multiple world records in the 6 - 7m diameter range were broken on the job, including "Most Feet Mined in One Day" (124.9

m), "Most Feet Mined in One Week" (515.1m), and "Most Feet Mined in One Month" (1,754m).

"It couldn't have been done without the guys in the tunnel working so well together while still keeping safe," said Shea-Kiewit project manager Stuart Lipofsky. "SK rebuilt the machine into a hot-rod; they built a machine that was over-engineered for the rock." Shatters, among many others, believes that the machine's robust rebuild is responsible for the impressive rates and early breakthrough.

One major challenge was encountered; groundwater inflow that was beyond what was originally anticipated.

Near the mid-point of the tunnel, heavier than expected ground water inflows caused a slowdown in production. For the remainder of the project, much of the tunnel contained a few inches of water. This led to decreased production rates due to safety precautions and water clean-up.

Now that the main tunnel of the DRTC is complete, the project is moving into its next phase, which includes constructing a 5.5m diameter cast-in-place concrete liner.

The remainder of the overall tunnel system includes boring a network of four additional tunnels totalling over 27km to reduce the wastewater overflow into the White River, Fall Creek, Pogues Run and Pleasant Run waterways. Solicitation for the next two tunnel phases is anticipated to occur in mid-2016.

Based on the terms of Indianapolis' Federal Consent Decree, the entire tunnel system must achieve full operation by the end of 2025.

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## PADDINGTON EXCAVATION REACHES CROSSRAIL TUNNEL

**GREAT BRITAIN** — Costain Skanska JV has excavated down to the new Crossrail tunnels, breaking into the top of the tunnels 16m below ground level, as part of construction of the new station at Paddington.

Costain Skanska will excavate the earth between the two tunnels creating a large open station platform level. Once excavation is completed, they will start building the station platforms and laying the track bed.

Andy Mooney, construction manager, Costain Skanska JV said: "Reaching the tunnels marks an important phase in the construction of Paddington station. The excavation down 16m underneath Eastbourne Terrace will allow us, once we have removed all of the 2,640 individual tunnel segments, to start the

construction of the platforms and track bed."

Tunnelling machines Phyllis and Ada built the new train tunnels through Paddington at the beginning of 2013 ahead of completing their 6.8km journeys to Farringdon in autumn 2013.

Following the completion of the platform and track bed construction, system-wide contractor ATC (Alstom, TSO & Costain) will commence fit-out of the new tunnels with track and other rail infrastructure.

The new Crossrail station is being constructed adjacent to the existing Paddington National Rail station under Eastbourne Terrace.

The 250m long and 30m wide spacious station will include a 120m long glass canopy. A Cloud Index artwork by artist Spencer Finch will be embedded into the canopy.

### Final breakthrough of Hallandsås tunnel achieved

**SWEDEN** — The final breakthrough of tunnelling work at the Hallandsås Tunnel, Sweden, has been achieved. The project used a Herrenknecht TBM to cut through the last meters of rock to the target shaft after eight years of tunnelling. The projects aim was to expand the railway route along the Swedish west coast from Malmö to Göteborg, Sweden.

Due to its geology, the project occupies a top position on the list of tunnel projects with extremely complex ground conditions. Large sections of the abrasive rock formations, mainly gneiss and amphibolite, with high rock strengths of up to 250MPa are extremely fissured. In addition, the tunnel is exposed to extreme groundwater pressures of more than 10bar on large parts of the route.

For the mechanised tunnelling Herrenknecht developed and delivered a specially adapted TBM for the two remaining 5.5km sections of the 8.7km long Hallandsås Tunnels.

The machine was designed to work in both the closed slurry mode with hydraulic removal of excavated material and the open hard rock mode with belt conveyor removal. Permanently installed drilling and injection tools ensured water inflow could be controlled by grout injection when needed.

As part of a comprehensive test series, the sealing system of the machine was designed to withstand a groundwater pressure of up to 13bar.

Werner Burger, the head of the design department for traffic tunnelling at Herrenknecht said: "The machine design for Hallandsås was both a response to the extreme project requirements and a large technological advance: the concept aimed to provide a hard rock machine with the potential to work safely and efficiently in loose rock and even under high groundwater pressure if needed. "Hallandsås has set the right course for later projects."

The Swedish-French joint venture of Skanska and Vinci started tunnelling on the first Eastern tunnel in September 2005.

### Turkish Prime Minister wants Eurasia tunnel finished ahead of time

**TURKEY** — Turkish Prime Minister Ahmet Davutoglu has convinced the contractors of the Eurasia Tunnel to speed up construction and complete the project earlier than planned, amid growing concerns over safety weaknesses in the sector, the country's national press reported recently.

Istanbul's Eurasia Tunnel and roadway pass began construction in January this year and was planned to be completed in August 2017. However, the construction will reportedly be completed by December 2016, following negotiations with the contractor company's representatives.

Davutoglu visited the project site in mid September. At the time the length of the constructed tunnel reached 920m. Davutoglu said at the time that "completing the project in the shortest period of time, but in the safest way, will give us great happiness. The depth of the tunnel reaches 106m underwater at some points, while the total length of the tunnel is 5.4km and the length of the

transit pass is 9.2km. The Eurasia Tunnel is Turkey's second underwater project in Istanbul after the Marmaray railway.

### Bhutan green light

**BHUTAN** — Except for an undefined weak zone, the Thimphu-Wangdue tunnel road has been found feasible, as of last month.

An aerial survey report of the geology identifies Nabisa in Wangdue, where the tunnel ends, as the weak zone.

A Danish company Sky carried out an aerial survey using a helicopter last April. Another survey was carried out on site.

An expert team from the Norwegian Geotechnical Institute (NGI) and the geology and mines department under Bhutan's economic affairs ministry will soon visit Nabisa to locate sites for boreholes to investigate the underground earth strata to determine the weak zone.

The department's head of seismology and geophysics division, Dowchu Drukpa, said the report is as good as final.

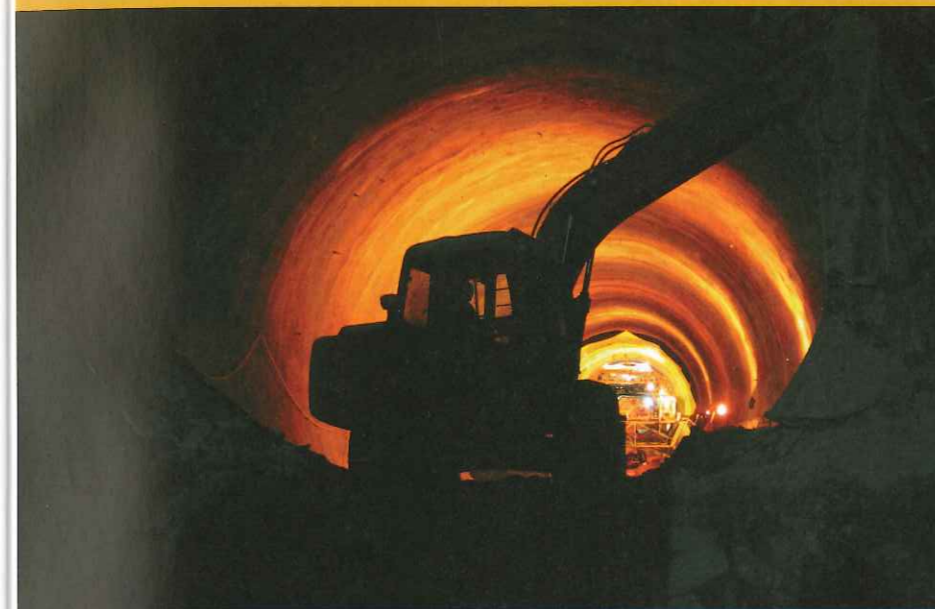
"They wanted to incorporate the geological mapping that we did with NGI earlier this year to the survey results," he said.

"While the underground structure is suitable for tunnel construction in most parts of the alignment, the only concern is that there is a weak band near the portal at Nabisa."

Two options were identified after the preliminary survey. The first, a 10km tunnel from Yusipang to Nabisa, although shorter, is steep, with 7 per cent gradient towards Thimphu.

"The second option, a 15km tunnel between Sementokha and Nabisa, has a gradient of less than 3 per cent," Dowchu Drukpa said, adding that the elevation could be lower at the portal or tunnel end at Nabisa."

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**Hayward Baker names new San Diego project manager**

USA — North American geotechnical construction company Hayward Baker Inc. (HB), recently announced the addition of Matt Redfern to the company's regional office in San Diego, California as a project manager.

Redfern's responsibilities include procuring and managing earth retention and drilling projects throughout the western United States.

He is also responsible for day-to-day management of projects, estimating and proposal preparation, plus contract negotiations.

Redfern has specialised in heavy civil infrastructure, managing roadway, bridge, and railway projects. He has expertise in various drilled foundation support, ground improvement, and earth retention technologies, including drilled shafts, cast-in-drilled-holes (CIDH), secant piles, soil mixing, tiebacks, and shoring.

Dan Cadenhead, senior VP, Western Region said: "Matt is a welcome addition

to an already-strong project management team. Matt brings a unique and valuable general contractor perspective to the table, and has already shown to be an exceptional and supportive team member."

**Keller's CEO to retire**

USA — Keller Group has announced today that its chief executive, Justin Atkinson, has informed the company's board of his intention to retire from Keller at the end of 2015. The company has initiated a process to identify a successor to the role.

Roy Franklin, Keller's chairman, said: "Justin is a highly effective chief executive of Keller. Under his leadership, and with the support of a strong executive team, the business has undergone significant transformation and operational improvement with compound TSR growth at around 17 per cent in the 10 years since Justin's appointment as chief executive. The timing of this decision provides Keller with

continuity of leadership and the necessary time to search for and appoint his successor in an orderly handover."

Atkinson added: "Since I joined Keller in 1990, the group has grown significantly, especially in international markets with the group now working in over 40 countries. Particularly during recent years, this has meant an ever increasing amount of overseas travel, which is not something I can continue to commit to. I have therefore informed the board of my intention to retire from Keller at the end of 2015, when I will be 55. In the meantime, I shall continue to work diligently with the executive team to deliver the group strategy."

**Kholongchu hydropower project to kick off in December**

BHUTAN — Construction of the much anticipated 600MW Kholongchu hydroelectric project (KHP), in Trashiyangtse, is expected to begin by December, project officials said.

KHP authorities

recently floated tenders for the construction of approach roads to the main components of the project, which include the dam, headrace tunnel and powerhouse.

Deputy project manager, D.K. Khandal, said tender documents for all works would be made available by 1 October.

"After the bidders submit their quotations, it would take about a month to evaluate the bids and award the work," he said.

After the winning bidder signs the agreement for the project, a mobilisation time of one month will be provided to the bidder.

"We're expecting the road constructions to begin by December, provided we don't encounter any problems," D.K. Khandal said. "If bidders don't qualify and we're required to re-tender the works, it would take more time."

Construction of the project components will begin after the roads are connected to the sites. Floating of tenders for the project components would depend on the time taken to complete road construction.

"We would schedule the floating of tenders such that construction of the components would start as soon as the roads are completed," D.K. Khandal said.

The whole project construction is expected to take eight years to complete.

**Land acquisition delays Ciliwung River tunnel**

INDONESIA — The construction of a tunnel, which will connect the Ciliwung River in Bidaracina, in East Jakarta, with Jakarta's East Flood Canal, East Jakarta, has been hampered by land-acquisition issues, according to local media reports.

Construction of the tunnel began on 9 May by state-owned PT Wijaya.

**BB SELLS PB TO WSP**

GREAT BRITAIN — Balfour Beatty announced last month the sale of its professional services division, Parsons Brinckerhoff, to WSP Global Inc. for a cash consideration of USD 1,352.5M. The sale price assumes cash of USD 110M is retained within Parsons Brinckerhoff.

The sale is conditional upon the approval of Balfour Beatty shareholders and is subject to certain antitrust and other approvals.

Completion of the sale of Parsons Brinckerhoff is expected in the last quarter of this year.

Following the sale, and the recent revaluation of the PPP portfolio, the group's key strategic priorities include restoring the value of the UK construction business, including progressively returning it to peer group margins; continuing to build on the good performance of the investments and services businesses; leveraging the growth opportunities in US buildings, US civils, rail and power, and the Group's Far East and Middle East Joint Ventures; realising further indirect overhead savings and shared service

efficiencies across the Group; and continuing to assess all other value creation opportunities.

Steve Marshall, executive chairman of Balfour Beatty said: "The Board believes that the sale price of GBP 820M (USD 1,352.5M) delivers both a significant return on our original investment and a compelling level of value creation for shareholders, which remains the key focus of the board. The sale of Parsons Brinckerhoff follows the recent revaluation of our investments portfolio, which underlines the potential of this division to create value internally and across the Group.

"In the US, our core construction business is well positioned in a recovering market. In the UK we see the potential for margins to progressively recover to peer group levels. Our services business, meanwhile, is well placed to benefit from the growing investment in infrastructure.

"Together, these elements will provide a strong foundation for an incoming group CEO to take the company forward."

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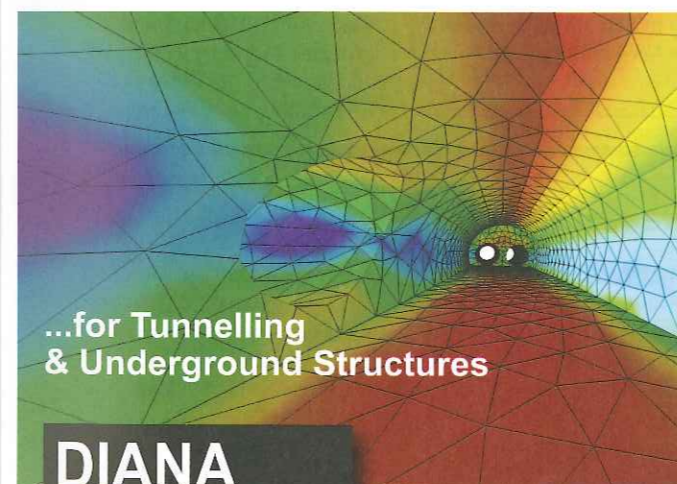


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## WATERVIEW HALFWAY DONE

**NEW ZEALAND** — The first of the twin 2.4km long road tunnels on the NZ Transport Agency's Waterview Connection project has been completed. Alice, the project's 14.4m diameter Herrenknecht EPBM, broke through on 29th September, at the end of her 10-month journey from Owairaka to Waterview.

The tunnel Alice has built is the tenth largest diameter tunnel in the world and the longest road tunnel in New Zealand. Alice is 90m long and weighs 3,100t.

"This is a fantastic achievement," said Brett Gliddon, NZ Transport Agency's highways manager for Auckland. "Our construction partners on the Well-Connected Alliance completed the breakthrough safely and ahead of schedule."

"It is a huge engineering feat for New Zealand, one that is attracting worldwide attention. It demonstrates that with local and international experience and expertise, we can deliver infrastructure to equal the best in the world."

Alice will now be turned around to bore the northbound tunnel. The cutting head and its three trailing gantries will be disconnected and each piece taken one at a time from the completed tunnel and turned.

Tunnelling is expected to resume early next year when all the TBM's parts are in place and reconnected.

The conveyor system that removes excavated

material and other services required for the machine's operation will also be turned and will follow Alice as she journeys south. By the completion of the second tunnel, they will extend the length of both tunnels – nearly 5km.

A fourth gantry, which operates independently of Alice to install a culvert on the floor of the tunnel, will be the last to be turned. This culvert will carry the services needed for operation of the tunnels once they have been completed.

The TBM's drive south from Waterview to Owairaka is expected to be completed in about October next year.

Approximately a year of work will then remain to complete the mechanical and electrical fit-out of the tunnels, including completing ventilation buildings at both ends and constructing 16 cross passages to connect the tunnels.

The entire project – which also involves building the surface connections to the existing motorways, 9km of new cycleway, new community amenities such as walkways, playgrounds and skateparks, and planting approximately 150,000 trees and shrubs – is due to be completed in early 2017.

The Waterview Connection is one of five projects to complete the Western Ring Route as an alternative motorway to SH1 through central Auckland and across the Auckland Harbour Bridge.

commander of the Royal Thai Air Force.

"Private investors' participation in development is important. Not only is there the opportunity of investment, but local businessmen can also feel a sense of ownership and responsibility for the project."

However, ACM Prajin rated local approval of the projects as most important.

"Local acceptance is very important. The project must not change their lifestyle, environment or culture," he said. The Patong tunnel project has been plagued with complaints from locals, many of whom voiced concerns of being forced from their ancestral homeland.

### Tahrir underground car park opens

**EGYPT** — An underground car park was due to open in Cairo's Tahrir Square in early October, officials said.

It was built on 20,000 square metres of land and is expected to hold 1,700 cars and 24 buses. It consists of four underground floors.

### Patong tunnel project costs overrun

**THAILAND** — The Patong tunnel project, to be located on Phuket Island and now slated to cost more than THB 10bn (USD 300M), is to be accompanied by a flyover to prevent a bottleneck at the Thung Thong Intersection in Kathu, according to a report published in the Phuket Gazette.

"Of the three options considered, we have decided for the final plan to include the flyover," said Aiyanut Tinaphai, governor of the Expressway Authority of Thailand (EXAT).

"The Ministry of Transportation assigned us to oversee the project two years ago. It has passed the Environmental Impact Assessment [EIA] and the final plan will be submitted

to the EXAT board this month."

The final plan to be presented will be for a 3.98km stretch of road, 1.83km of which will be tunnel. It will have one lane both ways for cars and the same for motorbikes, Mr Aiyanut said.

The current estimated costs for the project has risen from THB 9.57bn to THB 10.49bn baht.

Transport Minister Prajin Jintong, who was present at the meeting outlining the major transportation projects on the island, encouraged private investors to take part in large infrastructure projects in Phuket.

"Big projects such as the Patong tunnel and the proposed light-rail project need a lot of money to come to fruition," said Air Chief Marshall Prajin, who is

## News briefs

### MALAYSIA

The ambitious undersea tunnel project that is supposed to connect Penang island with mainland Malaysia may never take off as planned, as one key member of the consortium has pulled out. The announcement was made on by consortium member Astral Supreme Bhd on behalf of its unit Astral Supreme Construction Sdn Bhd (ASC) – stating it is "unable to find consultants who could undertake the project within the budget and the funding requirements".

### SOUTH KOREA

The government has launched a team to investigate sinkholes that have appeared in southern Seoul and other areas nationwide. A special inspection team, formed by the Ministry of Land, Infrastructure and Transport, will look into 'risky' areas where sinkholes can cause serious damage. The inspectors will work with the Korea Institute of Geo-science and Mineral Resources and the Korea Institute of Civil Engineering and Building Technology. The team will inspect Seoul subway line Number Nine and a Gyeonggi Province rail project, which are currently being built. The investigation will be focused on changes of the ground state, underground water levels and whether builders have followed safety rules during their work.

## BAKERLOO LINE EXPANSION UNVEILED

**GREAT BRITAIN** — Boris Johnson, mayor of London, and Transport for London (TfL) recently launched a public consultation to seek views on the extension of London Underground's Bakerloo line, which could run from Elephant & Castle towards New Cross, Lewisham, Bromley and Hayes.

With the capital's population expected to reach 10 million by 2030, TfL and the Mayor believes the extension will help support anticipated growth in south London by providing improved transport infrastructure and enabling regeneration in a number of the mayor's key opportunity areas.

Two routes for the project have been identified. One via the Old Kent Road to support major development plans for this area. The other route option being consulted on would go via Camberwell and Peckham. Beyond Lewisham, the line could then link onto the existing Network

Rail line using the South Eastern rail line to Beckenham Junction and Hayes via Ladywell and Catford. Finally, there is also an option to extend the line further on to Bromley town centre.

TfL stated that the route options for the extension have been identified as they improve connections to areas less well served by public transport. The proposed extension would run through a tunnelled section from Elephant & Castle to Lewisham.

The cost of the extension is estimated at up to be GBP 3bn (USD 4.8bn). TfL would work with the Boroughs along the route of the extension to explore opportunities for generating funding for the extension from new development. The public consultation will run until 7 December 2014.

Johnson said: "An extension of the Bakerloo line is one of my top priorities and I have asked TfL to bring forward

these plans at pace. It would provide a vital new transport link for the people of south London and help to spur jobs, new homes and regeneration in this part of the capital. It has huge potential to breathe a new lease of life into a swathe of London's opportunity areas, as well as freeing up capacity on national rail lines. As London's population continues to rise it is essential that we expand the transport network in this way if we are to meet Londoners' needs and ensure our city's continued competitiveness and success."

Michèle Dix, TfL's managing director of planning, added: "This is an opportunity for local residents to help shape an extension of the Bakerloo line which will deliver much needed transport infrastructure to south east London. We're looking at two possible routes for a tunnelled section, as well as a possible extension to Bromley town centre and want to hear people's views."

### JICA recommends metro option for Manila

**PHILIPPINES** — The Philippine government should consider other mass transit solutions to address worsening congestion in Metro Manila, including a USD 700M metro system on Edsa to complement the busy Metro Rail Transit Line 3 (MRT 3), said an official of Japan International Cooperation Agency.

Shuzuo Iwata, chair of Japan's Almec Corp. and a Jica project manager, said on 17 Sept. 2014 that a subway rail line on Edsa would be a viable solution as existing mass transit services would not be able to cope with rapidly increasing demand.

"The MRT 3 is small in capacity from the very beginning compared to demand," Iwata said at the sidelines of the Asian Development Bank's Transport Forum 2014. "It was a wrong choice of system. If we assume that it cannot be removed, you can only expand capacity [there] by 20 percent."

That was the reason why

the development agency was pushing its so-called PHP 2.6tn (USD 58bn) dream plan to decongest Metro Manila by 2030.

"It's really unfortunate that people [using MRT 3] have to wait so long... The waiting time is much longer than the traveling time," he said.

According to Iwata, final studies have yet to be made, but such a subway system is estimated to cost between USD 600M and USD 700M, and may be built in five years.

"It's not expensive for the Philippine economy. The government and private sector can finance that," said Iwata.

New projects, such as the proposed North-South subway line are crucial in supporting the current pace of economic growth, he added.

Iwata said the proposed subway should be part of several infrastructure deals the government must implement, like the expansion of the Light Rail Transit Line 1 to Cavite and the extension of the LRT 2 line.

The government recently awarded the LRT-1 Cavite extension project under its public-private partnership program.

The project is expected to be completed by 2019. Economic losses that could be attributed to the traffic congestion in Metro Manila today was estimated at PHP 2.4bn (USD 54M), Jica noted in its study. That figure could hit PHP 6bn (USD 134M) a day by 2030 if the government failed to intervene.

Preliminary analysis in the study showed that the average low-income group households have to spend no less than 20 percent of their monthly household income for transport. Without intervention, traffic demand will likely increase by 13 percent in 2030, and transport cost may be 2.5 times higher, Jica said.

### Hangzhou Metro Line Five given go-ahead

**CHINA** — Construction is set to begin by the end of the year on the fifth metro line in the Chinese city of Hangzhou

following the approval of the project by the Zhejiang provincial government.

The 48.6km, 36-station line will link Sci-Tech Island station in Yuhang with Xiangzhang Road in Xiaoshan, and is due to be completed in 2019. Hangzhou Metro Group is implementing the Yuan 35 billion (\$US 5.69 billion) project as a public-private partnership (PPP).

The PPP model will also be used to build the initial phase of Line 6 from Xihhu to West Xiaoshan. Construction is due to begin on the 27km line next year and will take four years to complete.

What do you think?  
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to the editor and join  
the debate



# BOLD DECISIONS

The giant of world tunnelling also dominates the list of wealthiest contractors, but key investment decisions are required to determine the future shape of cities, and international partnerships. Tunnels speaks with **Paul Jenkins** and **David Gutteridge** of Mott MacDonald

**A**T THE time of writing, China is grappling with pro-democracy protestors in Hong Kong. The demonstrations are a reaction to Beijing's plans to vet candidates for the Special Administrative Region's 2017 leadership elections. Hundreds of arrests have been made, while in Taiwan, solidarity protestors have gathered outside of the Hong Kong cultural office. China has a dilemma. While it fears the protests will spread to the mainland, it is reluctant to be seen as authoritarian by sending troops to confront students. The mega-state is also bound by a 1984 agreement with Britain to grant Hong Kong a high degree of autonomy for 50 years after the 1997 handover. As *Tunnels* goes to print, Beijing is treading softly, leaving matters to the police, and acting through state-run media.

## GOING GREEN WITHOUT A SCENE

But bold moves are more the superpower's métier. And bold investment decisions will be needed to address future requirements according to Mott MacDonald's China MD, Paul Jenkins. "Take Taiwan. Taoyuan City's Green Line is potentially a very interesting upcoming project. CECI did the concept design, and the plan is for the northwest end of the line to link in with an Aerotropolis; a new urban area built around a central airport.

"The route is 5km tunnelled, with the remainder elevated, and is due to open by 2022. However, my view is that by then, the world may have begun to change with regards to



public transport use.

"I have given a number of presentations to the city's mayor giving my concerns. We have to wake up to the fact that the world will change in 20 years. Metro is meant to last 100 years and we've got to think about how appropriate the infrastructure we build is. Aerotropolis will be a 'Smart City'. It likely won't have cars going freely around, as they block all alternative transport and blight a city.

"A modern solution is needed, a fully integrated transport system with shared use of space; station and public space combinations. This sort of thing won't be in place by 2025, but might be by 2035. And it is inconvenient to interchange with deep metro."

Jenkins adds that the expected passenger flow of 4,000 per hour is more in the domain of light rail requirements, and that the capital cost would not be paid off by patronage, and would be a continual drain on resources.

However, with a November election looming, a u-turn by government is not likely. In fact, to show progress, Project Construction Management tenders have gone out as EPC tenders will not come back in time.

Jenkins believes there is a lot of opportunity for value engineering, particularly when the long term is considered.

## HIGH-SPEED JITTERS

Back on the mainland, high-speed rail projects are still a major portion of the work engaged in by foreign companies. At any one time, China has 5,000km under construction, and has a rule that any route designed to run trains that exceed 350kph requires foreign construction supervision.

A series of four high-speed rail lines are expected to be released in the near future, and there was a lot of industry fear that Chinese experience might lead to this rule being dropped. Fortunately, and to general surprise in the industry, this didn't happen.

Jenkins adds, "On balance the clients felt good value was obtained from the present system, and so it continues.

"In the last few years, longer routes between cities that were on hold have been resurrected, we have another high-speed rail push. The government has announced 80 PPP jobs recently, one of which is HSR. That's unusual, allowing the private sector to invest in a line."

## LOCAL SUMMARY

David Gutteridge, Mott MacDonald's practice leader for transportation gives an overview of the wider area. "In Singapore we have had the cable tunnels, and what is now called the Thomson East Coast Line as the most significant work on the island. In Malaysia, it is Kuala Lumpur Lines One and Two, and in Hong Kong we have various MRT projects, mostly in a design and construct format.

"In Indonesia, our major project is the Jakarta MRT with a Japanese contractor. And in China of course the most significant work we have is on the high-speed rail routes. Usually very big projects.

"In terms of upcoming work that we're looking at, in Singapore there is the Cross Island Line, which Arup has been undertaking the initial studies for, as well as the Jurong Region Line.

"In Hong Kong, the West Island Line is approaching completion. Some 40 per cent of the company's turnover comes from transportation, so these projects are significant to us. There's a lot of work in the region, and obviously a lot of these sort of projects take a significant amount of time.

"There's more work than available resources, and so one of our key activities is investment in future project leaders. On the



Above: China faces demanding passenger numbers

Opposite: The Taoyuan region is already highly developed

job training for these young engineers is key."

## INTELLIGENT DESIGN

Gutteridge adds that something he is seeing more and more across transportation is the uptake of BIM. In tunnelling terms in China, Jenkins is not so sure however. "BIM is certainly being talked about a lot here. We're doing a factory that makes use of it, and we've looked at a Shanghai Metro station, but in the end the Design Institute did it themselves. It is early days for BIM here, there's not much of it in evidence, but I expect to see a rapid uptake."

Extensive use of smart cards, for example in Taiwan public transport, has also allowed for the creation of very accurate traffic patterns. The local "Easy Car". It's possible to tailor a system to match the specific local requirements.

## EXODUS

The world is short of engineers. The Tunnels office in London is regularly blasted with press releases lamenting the local shortfalls of engineering graduates, but the trend is worldwide. "Except for China," says Jenkins. "If the world comes out of recession in a big way, there are not enough engineers to cover the amount of work that could result. Except in China. And we may see the Chinese replacing some of the internationals.

"We are leaving China with Chinese partners in some cases now. For example, we have rail work in Mexico and Uganda, and opportunities in the power sector in Central Europe. The companies bring the money with them. And there are so many opportunities, that we build relationships wherever we can"

editor@tunnelsonline.info

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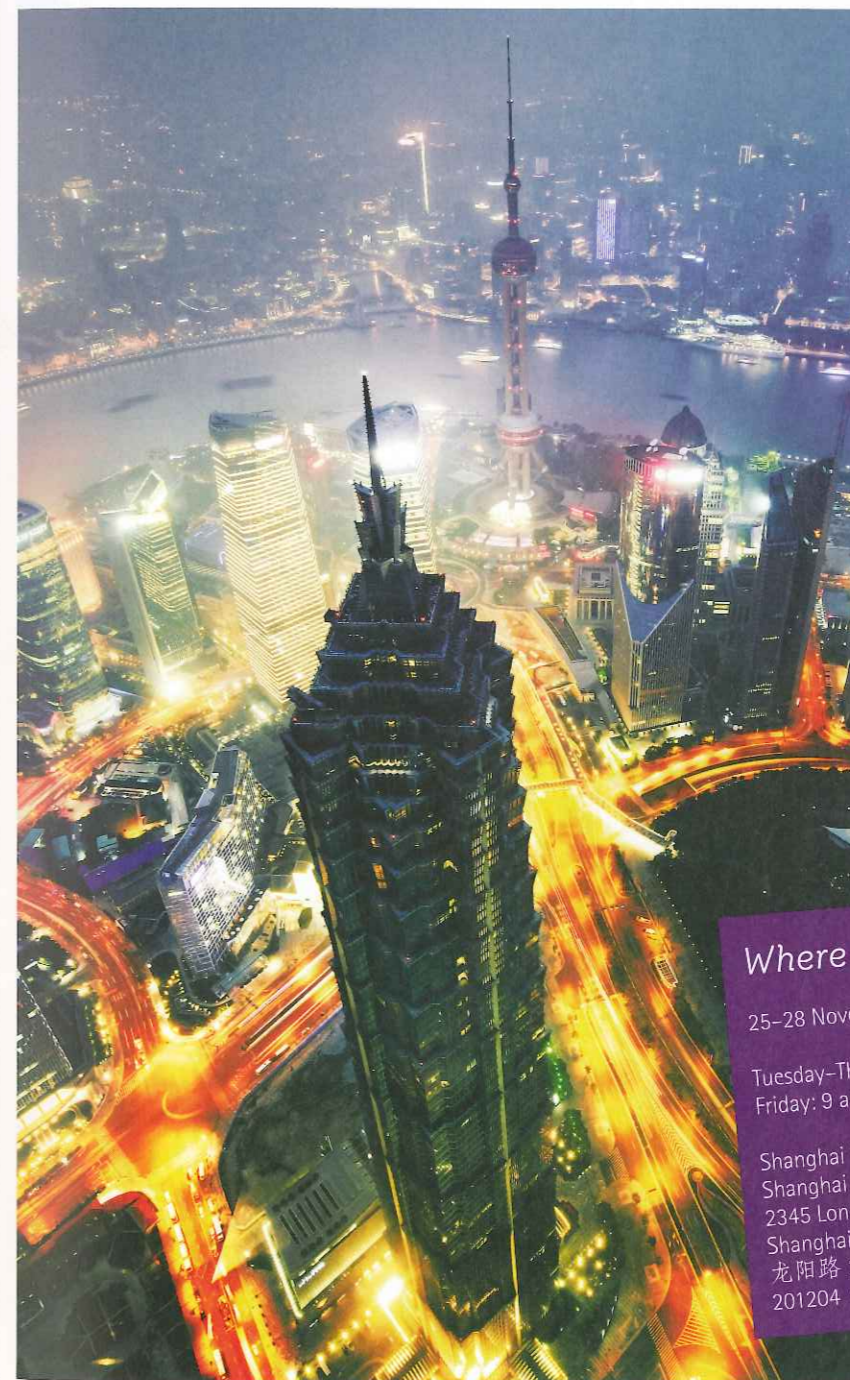


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# GOING THE DISTANCE

Robust machines needed for epic Liaoning Water Transfer Project. **Desiree Willis**, Robbins technical writer reports

## 120

The network length in kilometres that the Chinese government has invested resources into realising

## 102

The amount of rainfall in mm that fell on Shenyang City last year, constituting the worst drought in 60 years

**N**ORTHEASTERN CHINA'S Liaoning Province and its largest city, Shenyang, are experiencing the worst drought in over 60 years. With just 102mm of rainfall in the summer of 2014, the Chinese government resorted to what it calls 'artificial rainfall', consisting of planes flying over farmland and dispersing large amounts of water. Even with those measures, the larger problem of drought in the area requires long term planning to fix. The Chinese government has done just that, by investing in a massive network of water transfer tunnels totaling over 120km in length for irrigation and drinking water. Excavated entirely below ground, the mammoth conduit is testing the limits of TBM design and excavation.

### SUPER-LONG WATER TUNNELS

The Chinese government commissioned the project, known as the Liaoning NOW Water Transfer Project, in nine lots, designated T1 through T9 (for Tunnel No. 1 to 9, etc.). Each lot, except for T7, is utilising a TBM to bore two sections of tunnel ranging from 6.5km to 8km in length each. Lot T7 is utilising drill and blast. Lots T1 and T2 purchased new Herrenknecht Main Beam machines. Contractor SinoHydro Bureau 3, responsible for lots T3 and T4, elected for new Robbins Main Beam TBMs, 8.53m in diameter. Similarly, T5 contractor Shanxi Hydraulic Engineer Construction Bureau ordered an 8.53m Robbins Main Beam. Chinese equipment supplier NHI contracted with Robbins to supply Main Beam machines of the same diameter for T6 and T8, and a rebuilt Robbins machine was provided for lot T9. All eight machines, including the Herrenknecht TBMs, were ordered with Robbins continuous conveyors for muck removal. The difficult and long tunnels were found to pass through mainly granite and migmatite geology of varying abrasivity. Mountainous

*Left: A member of the Robbins Field Service team inspects the gripper of one of the Liaoning NOW Main Beam TBMs*

### Desiree Willis

Desiree has covered a range of topics for *Tunnels*, as Robbins' technical writer



terrain including valleys and rivers meant the machines needed versatile ground support. Cover was found to vary widely, from as little as 97m to as high as 590m at T6.

#### LONG DISTANCE TBM DESIGN

In order to design machines for such conditions, consideration must be given to the harsh aspects of tunneling in hard rock over long distances. "This can be broken down into what can be done at the TBM design stage, and what can be done during TBM operation and maintenance," said Brian Khalighi, Robbins Vice President-Engineering.

#### Cutterhead and cutters

Khalighi emphasised that much of the design centers around areas directly in contact with the rock face, namely, the cutterhead and cutters. High strength materials, wear protection on the cutterhead, and cutter spacing all affect cutterhead wear in dramatic ways. The cutterhead should be designed with regular cutter inspections and changes in mind. In terms of rolling disc cutter design, larger diameters are manufactured with larger bearings capable of withstanding heavier loads while also offering more wear volume. Larger (19-inch or 20-inch) cutters are preferable to smaller cutter diameters, such as 17-inch.

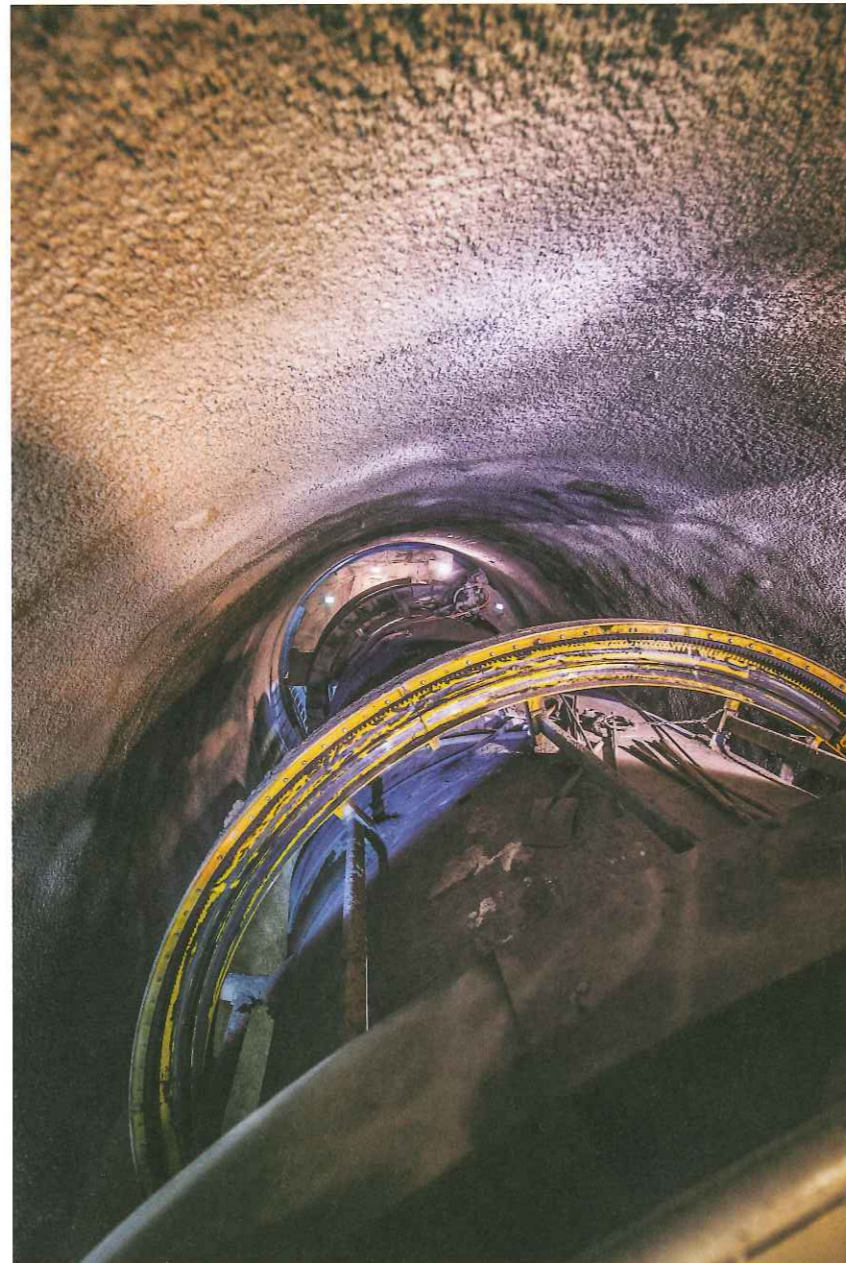
#### Main bearing and seals

Large diameter main bearings, with the largest possible bearing to tunnel diameter ratio, are capable of withstanding more load impacts and give longer bearing life. Robust seal design is also essential. "We have a proven seal design using hardened wear bands," said Khalighi. "Many other manufacturers don't use wear bands, and so as the TBM operates, it wears a groove into the seal lip contact zone. We have a sacrificial wear band that can be switched out or replaced, making repairs easier." The abrasion-resistant wear bands can be changed in the tunnel in the unlikely event of excessive wear, or can be relocated on the bearing to ensure that damage is not done to the TBM structure itself on long drives.

#### Load path

A uniform load path, from cutterhead to main bearing to cutterhead support,

**"Many other manufacturers don't use wear bands, so as the TBM operates it wears a groove into the seal lip contact zone"**



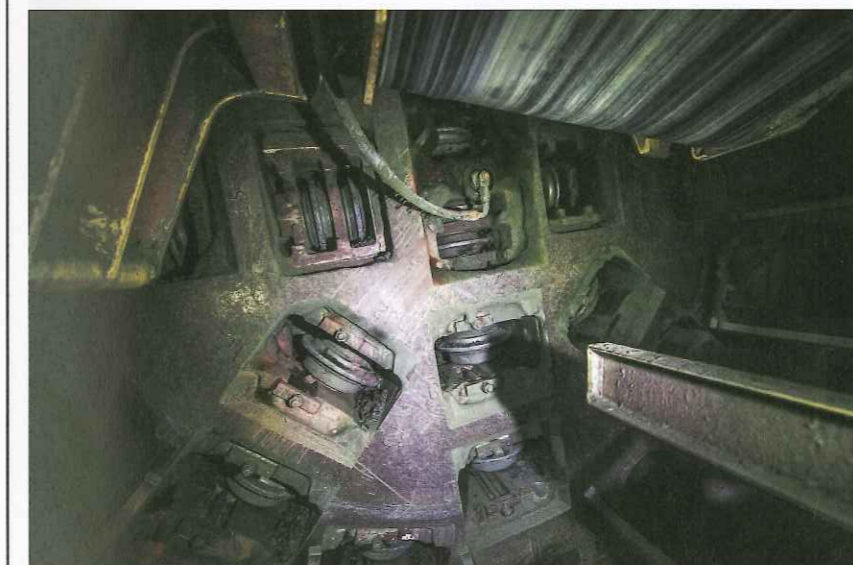
*Above: A final layer of shotcrete is applied to the Liaoning NOW tunnels*

is always desirable. However for long distance tunneling, the load path can be crucial as high stresses occur wherever the load path shifts. A cutterhead with a cone-shaped rear section can help with this problem by evenly distributing the load across the circumference of the main bearing.

#### Efficient muck removal

The path of muck, from the muck bucket to the chute to the machine belt conveyor, must also be as smooth as possible. Smooth muck flow not only increases efficiency, but also prevents the problem of re-grind on the cutterhead. It can also reduce wear on both the external and internal surfaces of the cutterhead.

Similarly, a smooth muck flow path all the way out of the tunnel is critically important. Use of continuous conveyors



*Above: Cutterhead design to optimise regular cutter inspections and cutter changes is critical for long distance TBM tunnelling*

limits downtime as compared to the downtime experienced when a locomotive and muck cars are used. As a tunnel gets longer, the time to transport muck cars in and out of the tunnel becomes less and less efficient.

#### Maintenance

Once the machine has been built, regularly scheduled maintenance based on tunnel length and geological conditions is key. Gear boxes, for example, may be designed for long tunnels but if it is known that the tunnel length will exceed the life of the gear boxes then planned refurbishment should occur

during tunnelling. Similarly, planned cutterhead changes and inspections should be a regular part of maintenance. One last important component of machine maintenance in long tunnels is oil. Fluids and hydraulics such as lube oil must be regularly checked for their quality and levels.

#### VERSATILE GROUND SUPPORT

A flexible ground support system was provided for all six Main Beam TBMs at Liaoning due to the long tunnel lengths and variable conditions. The machines are capable of installing a wide variety of ground support, from wire mesh and rock bolts to ring beams and McNally slats. The TBMs are the "first to be designed with McNally pockets during fabrication, and the first to use 20-inch disc cutters in China," according to Andy Ju, sales manager for Robbins China. The McNally roof support system, developed by C&M McNally for exclusive use on Robbins TBMs, is a unique solution: In the past, roof support fingers provided limited protection to the crew working at the front of the machine and also to a degree prevented damage to cutterhead drive motors and other equipment installed on the front of



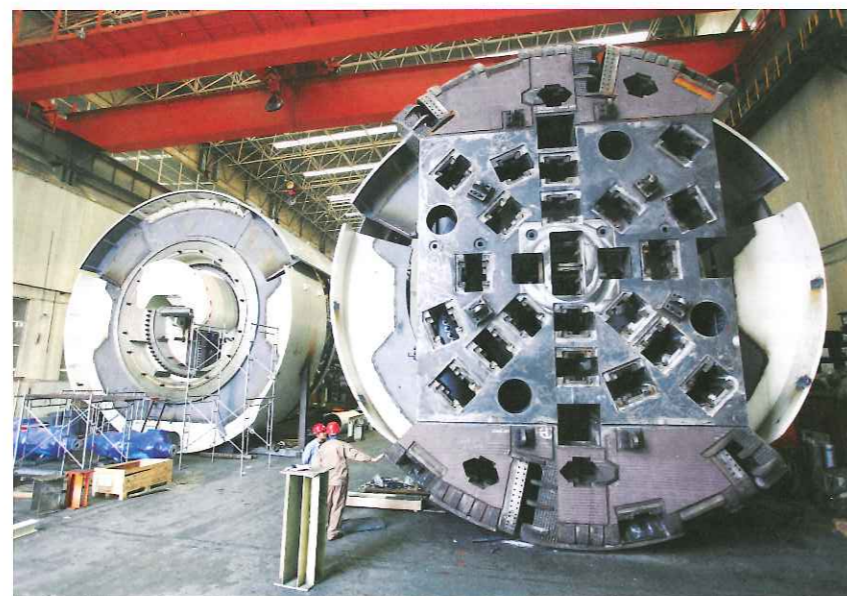
the machine. However, when poorer or blocky ground conditions were encountered these fingers would simply bend out of shape and more often than not the contractor would end up removing them altogether. With the removal of the roof support fingers, the bored tunnel is exposed at the back of the roof support where more effective ground support is easier and quicker to install. The fingers are replaced with a curved assembly of pockets known as McNally pockets, and as the TBM advances, workers load the pockets with steel slats that are then extruded during a TBM stroke. The slats are bolted in place, providing continuous and maximal support to the tunnel crown in difficult rock conditions.

Several other unique aspects were designed in order to accommodate multiple ground support options within an 8.53m diameter space. Materials handling takes place in the tunnel invert, requiring a 180-degree rotating backhoe scoop that can be moved out of the path of the cart. A bridge crane and jib crane pick up materials such as mesh panels, new disc cutters, etc. and transfer it to the bridge area. Invert cleaning is ongoing when the cart is not in place.

*Below: The TBMs feature versatile ground support systems and 20-inch disc cutters—the first time this diameter has been used in China*

The ring beam erector and roof drill system are both mounted on the same rail system, but are capable of independent movement. The ring beam erector consists of the assembly ring and expander. The rotating assembly ring is fixed axially and used to loosely assemble five ring beam components.

Once the components are loosely assembled and pinned to the assembly ring, the expander, which moves fore and aft, expands the components to a preset pressure against the



"The contractor at T5 has taken steps to **extend the coverage** of the original McNally system to the gripper shoes area and both side supports in case difficult ground is encountered"

tunnel wall. A sixth Dutchman piece is installed in the resulting space, and the ring beam with tightened connections is bolted to the tunnel wall. The assembly and expander can also be easily converted for installation of steel straps, rather than full rings. Previous assembly methods required that the fully assembled ring beam be transported to a pocket before being expanded against the tunnel wall. The method is not as fast, and does not give the flexibility often needed in changing ground that may require steel straps.

#### TBMS FLY THROUGH HARD ROCK

The machines were launched between October 2013 and February 2014 from adit tunnels, with the exception of the refurbished T9 machine, which was launched earlier in 2013. Robbins Field Service were at the site providing mechanical, electrical, and hydraulic system supervision, TBM operation during site assembly and commissioning, and training on proper operation and maintenance of the machine.

Each machine will break through into chambers on its first section of tunnel, and will ultimately break through into a disassembly chamber underground.

As of 23 August 2014, the T9 machine had broken through into its first adit chamber after having bored more than 7km. T5 had progressed the second farthest, at 5.8km or 36 per cent of the total tunnelling drive. Despite having started early in October 2013 and January 2014, the two drives at T1 and T2 had completed the fewest meters. Hundreds of bolts had to be replaced on the T1 and T2 cutterheads, slowing down the drives due to down time.

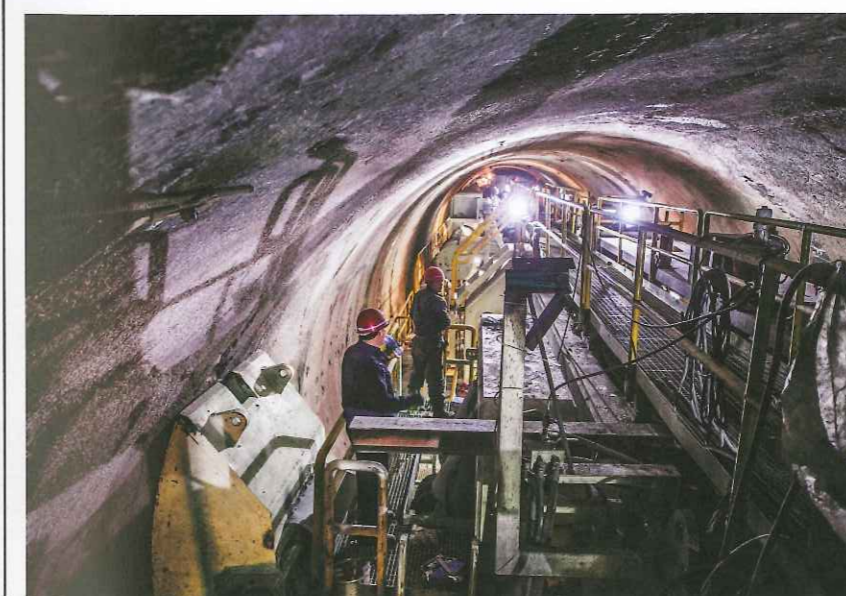
Cutter wear has been another issue due to a combination of abrasive ground, cutterhead design, and cutter spacing, with the T1 and T2 machines averaging 88 cubic meters and 338cu.m bored per cutter, respectively. Cutter life and stoppages for cutter changes have been so significant that the contractor has opted to test out Robbins 20-inch cutter discs in high wear areas of the cutterhead such as the gauge area along the outer circumference of the cutterhead.

Cutter wear at the other tunnels has been better—as high as

1,022cu.m bored per cutter at T5, where the machine is also averaging a healthy 618 m per month. Ground conditions have been difficult—T5 passes through four fault zones up to 10m wide, and passed under a river in a difficult section of hard rock. T6 has the most fault zones, with six faults measured at up to 20m wide.

At T5, fractured ground conditions have required the use of McNally slats to consolidate the ground in over 50 per cent of the tunnel. "This is the best and reliable ground support system we have ever used before," said an official with contractor Shanxi Hydraulic Engineer Construction Bureau. The contractor at T5 has taken steps to extend the coverage of the original McNally system to the gripper shoes area and both side supports in case difficult ground is encountered. The contractor will reinforce tunnel walls under the gripper shoe position by using a combination of McNally slats, ring beams and a top layer of shotcrete so the gripper shoes can react against the reinforced shotcrete face. The process should allow for fast and continuous boring without the need for continual reinforcement of the grippers. Some issues with the shotcrete system design have also prompted Robbins engineers to work with the shotcrete equipment supplier to develop solutions. Design specifications had called for a 6m long extendable boom, but the pulsation of the shotcrete pump during extension would cause deflection, resulting in inconsistent application to the tunnel walls. A cable pull-back system was designed as a temporary solution to solve the extension and retraction problem. Robbins engineers are now developing a brand new bridge-type system to solve all the problems permanently, which will be installed in mid-December 2014.

*Below: The Robbins machine at T5 has the highest rates of advance and best cutter wear on the project, averaging 618m per month and 1,022 cubic meters bored per cutter*



Overall, the machines are progressing well, with the continuous conveyors being a particularly important part of the overall system. Continuous conveyors transfer muck to adit conveyors between 600m to 1.3km long, which then load up radial stackers for temporary muck storage onsite. "The entire conveyor system is reliable, stable and efficient," said Li Xiao Han, a representative from the project owner. Tunnelling is expected to be completed on the massive project in October of 2015.

## BANGKOK METRO EXTENSION

Complex station works, and tunnel drives constrained by logistical and property issues are needed for the Blue Line metro extension in Thai capital Bangkok. Some of the stations are highly visible near the famous old parts of the city. Report and pictures by **Adrian Greeman**

### Going further in 2014

A complete subsurface construction source for the utilities industry



**Adrian Greeman**  
Is a former editor of and long-standing regular contributor to *Tunnels*



**A** DECADE AFTER the opening of its first underground metro line, Bangkok is in the middle of a major upgrade to its public transport system. The first, Blue, line is being extended with both above ground elevated track and new tunnelled sections. A series of other lines are either in construction or being readied, to expand the city links over the next half a decade

"Most of the new lines are elevated" says Christian Schulz, an engineer with German consultancy firm Dorsch Consult who is currently on secondment as executive project director for the Blue Line works. "That is obviously less expensive than tunnel, though it can sometimes bring complications with land acquisition, utilities and traffic".

The city's first ever line, the privately developed BTS Skytrain, is an elevated system and has proved highly popular since it was completed at the turn of the century. Running through the busy tourist Sumkamvit area and down to the river it has not only helped alleviate the severe traffic congestion that used to bring the city to a near standstill at times but has stimulated retail and residential development. Some extensions are being added to this. An airport rail link is also popular.

The Blue Line, built by the government's Mass Rapid Transit Authority was the city's first underground line however, running in a horseshoe shaped loop north to south, finishing near the central rail station. Opened in 2004 it took a while to develop its ridership in a city with a large poorer population for whom ticket costs are difficult. But there is a growing middle class and it has become well used; it is also an important contributor to city development. As the deputy director for the Mass Rapid Transit Authority of Thailand, Peerayudh Singpatanakul puts it "people are learning the habit of public transport".

The line will now be made into a complete circle, or rather an elliptical loop line, with the "missing" section completed up through the districts lying along the west bank of the Chao Phraya river. This section will be elevated, and so too will a 10.5km long westwards extension. But a 5.4km long connection across the river to the original underground at the south end will be in tunnel. There are four stations in this part, all underground.

As well as going under the river, a key reason for tunnelling here is that the alignment passes through or nearby some of the oldest and culturally most

## 381

The value in millions of USD of the design-build contract awarded to ITD in February 2011

important parts of the city, including alongside major temples and museums. These are part of the royal palace district and also significant as tourist sights. Towards the rail station end of the new tunnel it also runs underneath the Chinatown quarter, another bustling and important area. Elevated line would have been obtrusive.

"The new line is split into five major contracts," says Schulz "the elevated section to the north end, which is 11km long, the elevated western extension which also includes a depot works, trackworks, and then two tunnel contracts.

"The first of these is for a connection to the existing line at Hua Lamphong just outside the main railway station. A cut and cover excavation makes the link to the existing underground station and from there twin running tunnels are driven for 2.85km. There are two underground stations, the Wat Mangkon in Chinatown and the Wang Burapha closer to the old city."

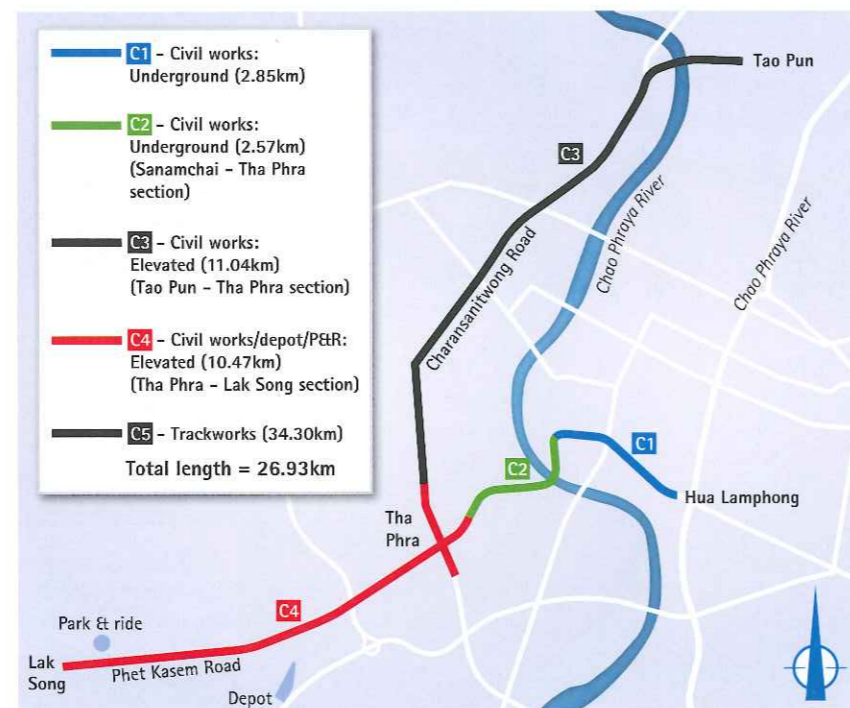
The contract was let to ITD in February 2011 on a design-build basis and is worth THB 11,441M (USD 381M)

The other contract continues the tunnels for another 2.7km and also includes two underground stations, the Sanam Chai, situated just close to the Thai museum and nearby a temple with Bangkok's famous reclining Buddha, and then on the far side of the river, the Itsaraphrat. It concludes with a cut and cover section with an incline for the track making the transition to elevated way.

The tunnels themselves are twin bores of 6.44m diameter, which after installation of 300mm thick segmental linings and grouting, leaves running tunnels with an internal 5.7m. They are both using earth pressure balance tunnelling machines for the work, a Kawasaki for Ch Karnchang and a Terratec, for ITD on the first contract.

Both have to pass through the very soft clay layers which underlie the city and into water bearing sand layers beneath. Bangkok's geology is notoriously difficult for building construction, requiring major deep piling for most structures through the very soft clay layers - like toothpaste most engineers say - into the firmer sands and firmer clay layers under that. The city has also had issues in the past with water extractions from the aquifers beneath which caused significant

Below: Figure 1, Route map for the project



Above: Tight working conditions have been a challenge

settlement in the past, though it has slowed up following a ban on unregulated water use.

Stations are conventional diaphragm wall box constructions, but relatively constrained by the narrow street pattern and the difficult property issues. These have caused some delays on particularly the first contract. For the ITD contract it also means double stacking the lines in the stations to keep the width down, with one of the stations deepened to 29m. First of the Ch Karnchang stations is also 29m deep.

The stations overall are 22m wide at the maximum point, with part of the station box, for concourses and escalator links, offset to one side and with a surface station building above that. It is the land purchases for the wider sections, which involve demolition of some buildings alongside the alignment which have held up some work. The tunnels themselves are kept below the street lines above.

There are also city imposed constraints on surface excavation for the two centre stations, one in each contract which has led to some unusual "pipejack roof" construction. "The area is part of the ancient settlement and has possible archaeological importance," says Schulz. A ruling says that previously undisturbed ground, mostly under the street must be left intact for the top 5m and so contractors have had to find a way to support the top layer while excavating underneath.

Thailand's two largest contractors won the work, Itai Thai Development, ITD for the Hua Lamphong section and Ch Karnchang on the continuation underneath the Chao Phraya river. Both started in March 2011 and both have had some



difficulties and hold-ups with the tunnel drives but both are currently in progress. Completion to a revised schedule is due in mid-2016.

"Fortunately the completion of the drives is not on the critical path" says Schulz, "which is determined by the rolling stock and signalling works contract, a sixth contract which is just at the start of procurement."

For Itai Thai, one of the main difficulties has been simply fitting its works into the congested street junctions around the main station and coping with limited site space. It is launching its drives from the end part of a cut and cover construction needed to link the tunnels to the existing line terminus. This requires work underneath one of Bangkok's busy roads which has required the contractor to split its worksite into three sections, one occupying the middle of a roundabout for the site depot, the next for TBM launch and spoil mucking from an access pit to one side, in front of the railway station, and a further site 200m away occupying a narrow strip in the main road, which serves as a segment store and materials depot. Engineers have to constantly cross the roads from one to the other, and ironically for once, the often slow pace of the traffic in Bangkok is a blessing.

But it makes work organisation difficult. "We have to use a just-in-time method to bring the segments from the storage area to the TBM access pit," explains Itai-Thai project manager at the main contract site Thavesak Rungpiriyadech.

Additionally he says, part of the work is being done underneath heavy road decking for the construction of the 170m long cut and cover box linking the old Blue Line to the new. An opening 18m by 18m at the far end of this is where the 15m deep tunnel access pit is located for the for the TBM work.

Tunnelling began in January last



year and somewhat before that was underway on the construction of the two station boxes, using diaphragm walls and top down excavation sequences. But property acquisitions have held up some of the station work and recently an extension of time was granted for the contractor to allow for the difficulties.

Most of Rungpiriyadech's attention is on the tunnelling however. The twin bores are being made in two drives, one after the other, passing under the street line and through the station boxes. The first drive is the lower of the two alignments for the stacked formation which means the TBM passes through the station boxes at a lower level first, which aims to synchronise with the excavation level they will have reached. The TBM leaves a segment lining which is removed by later excavation.

The drive is due to finish within the first of Ch Karnchang's stations just beyond the boundary between the two contracts. It is part of the other contractor's remit to prepare a reception space. Here the TBM is to be dismantled

and brought out by crane from above to return to the start box to set up again and carry through the second drive. The start point for that is a few metres in front of the first.

The Terratec TBM had all key parts produced in Australia and Japan and the final assembly of the TBM was done in Terratec's facilities in China. From there, the machine was shipped to Thailand by sea and the components trucked to site.

The cramped service pit is also used for the back up and mucking facilities. ITD is using a continuously advancing conveyor system also supplied by Terratec to bring the spoil from the machine and back along the tunnel where a small lateral conveyor loads it into big 5m long skips. These are lifted by portal crane and tipped into a handling container where any water can drain out loading into trucks.

But before all that could get into operation, as the first drive began in January last year, the contractor had to wait for some ground treatment for an initial section of the drive.

The tunnel line follows a shallow path initially because of the presence of two existing and quite major service lines close to the starting point. "There is a 3.8m diameter water tunnel to cross and a 1.5m sewer line," explains Rungpiriyadech.

That means it begins its drive in the Bangkok clay "which is

**"The machine has had to wait for progress on the station box itself."**



not even as firm as marine clay," he comments. The top clay is so soft that it needed firming up and for 380m along the first part of the tunnel line jet grouting was used to form a consolidated block through which the TBM could pass.

"We used a local company Kenber which made a 2m grid of 1.2m jet grouted columns" says Supavivat.

Once over the water tunnel the tunnel path drops down into firmer clay beneath the sand layers, although some treatment is still needed for the top of the tunnel line until machine is into the lower level completely.

There is also a point where the tunnel passes underneath one of Bangkok's famous canals (khlongs), and here 600mm diameter soil mixing columns were used for treatment instead of jet grouting, in order to avoid water contamination.

Further jet grouting has also been done at the station boxes, this time by subcontractor Trevi, to form sealed ground blocks for the TBM entry point through the station diaphragm walls.

These blocks have proved slightly problematical as they were probably not long enough says Schulz. The grouting through the shield skin may not have sealed off the annulus entirely,' says Schulz. "The TBM did not go far enough into the block and there was some water leakage," he says.

The drive up to that point has gone well enough though more slowly than hoped because the machines has had to wait for progress on the station box itself.

The machine pushed off a conventional reaction frame in the pit and for the early drive worked at a lowish pressure, as

little as 0.8bar according to Bunjerd Emnuch, a Terratec engineer onsite as advisor to the contractor on the TBM operation.

"As it has come into the waterlogged deeper sand layer this has changed and it needs to work at 2.5 bar" he says. "This sand layer is very fine" says Emnuch "and we need a lot of polymer to treat the ground forwards." Deeper in the clay beneath there will be less needed.

Guidance for the machine is by a Japanese Enzan system, "which includes monitoring equipment and data."

The machine installs a 300mm thick concrete segment ring comprising six segments and a key. Straight and left and right tapers are used for turns and the key is kept away from the invert. The design matches the original Blue Line.

Grouting is done just behind the machine shield through the segments themselves rather than from annulus grout points on the machine. There are lifting sockets in the segments to let them be pulled onto the TBM segments delivery track and these double up as grout points.

A significant number of bolts are used, some 25 around the rings to link one to the next and two bolts between each segment in the rings. "We use banana bolts" says Emnuch "which is for stability".

Segments are made at an ITD works about 150km outside Bangkok, which has to cope not only with the three ring shapes but four different levels of reinforcement in the mixes, to vary the strength of segments according to location. They are delivered by trucks, which must negotiate the traffic and are restricted for daytime movements to between 10am and 3pm. Segments go to the holding yard as the TBM shaft head can hold only a couple of rings; these are replenished from the holding yard whenever they are lifted down to the rail cars beneath by a big Demag portal crane. A Chinese made electrical locomotive uses battery power, which is sufficient for the relatively short drives being done.

Progress has been slower than possible, steady rather than record breaking, achieving around ten of the 1.2m long rings daily. That is because of the need to wait for the station box work to progress far enough to allow the tunnelling to go through. First of the stations was passed last summer – the TBM boring through the 1.2m thick diaphragm wall.

An unusual cone shape head with hardened steel blades mounted on four radial axes has been used on the ITD

*Above: Station excavation work is proceeding, ready to receive the TBMs*

## Roofing

To solve the excavation problem for the central stations both contractors have used piperof designs, a method used for small adits and underpasses before but not on such large scale. It is certainly the first use of the "pipe roof" method in Thailand says the ITD project director Pairach Supavivat.

The problem is to excavate the spaces for the station platform areas underneath the road line without disturbing the top 5m of ground. One solution might have been larger diameter tunnels for the 275m length of the station, connected to a narrower box to one side for the concourses, which could be built underneath demolished properties. But larger diameter tunnels, while considered, might have been difficult in the soft ground and high water pressure areas.

Instead a large scale pipe jack operation has been employed to create the track and platform areas. This involves the installation of a long row of interconnected steel pipes placed laterally across the station width underneath the road.

Around 150 steel pipes of nearly 2m diameter are used, driven from space available once the top down excavation has started at the side.

machine to allow the mainly soft ground machine to cope with the hard concrete. Terratec worked out this design in conjunction with Japan Tunnel Systems Corporation, a subsidiary of Japanese IHI Group. It is the largest head of this type yet made.

The cone, first developed for smaller microtunnelling work, allows the grinding of the 40N concrete to start centrally and work outwards, rather than requiring the full face to bore at once, imposing higher torques.

"We need to penetrate concrete at two ends of two stations and two interventions shafts, as well as the final station" says Emmuch from Terratec. "And then the same is needed on the second drive.

"On top there is the chance of meeting concrete pile obstacles that need to be cut, especially at points where we pass under bridges."

A recent hold up has been caused at an intervention shaft where the TBM was entering through a grouted plug. "There was some water ingress into the TBM chamber as the fine sands are under a considerable hydrostatic pressure," says Schulz. "Additional grouting was not successful enough and compressed air system was required."

But the TBM has now entered the shaft where the cutterhead blades were changed and has left on its way towards the final station.

Some water problems have also been experienced on the first drive for the Ch Karnchang contract. For this work the Kawasaki TBM was assembled at the far end of the contract.

"There is more space here because the transition point to the elevated section is longer and the cut and cover for the ramp downwards is on a greenfield site" says Schulz. The TBM set out and passed the first as yet unexcavated station and then continued towards the next station, passing underneath a khlong and heading towards the river. But last summer the machine stopped due to issues still yet to be evaluated says Schulz. "Operational issues seem to have contributed to some water leakage in the tunnel (between segments). Settlement control (by ground treatment) and repair of the TBM's effected electronic and hydraulic systems were time consuming.

A bulk head was built at the station meanwhile work has proceeded. Recently the TBM backup system of conveyors and segment supply rail has been reinstalled, work in progress when *Tunnels* visited in late February, and the Kawasaki machine has cautiously started its drive again "and was on target to reach and intervention shaft in June".

Schulz says that despite these issues the overall schedule will accommodate it, because the sixth contract sets the critical path. Meanwhile there has been other work ongoing at the four stations. These involve primarily conventional top-down excavation with diaphragm walls but some interesting additional works as well, including the pipejack roof works (see box) for the two centre stations, Sanam Chai on the Ch Karnchang contract and Wang Burpahpa on the ITD contract.

At Sanam Chai the contractor has also carried out a massive grouting operation to form a base slab to the station.

"The design intent was that the dense clay layer deep down would seal the base of the excavation," says Schulz, "with the diaphragm walls penetrating into it."

But as luck would have it, the clay layer at this point is not as thick usual in most of the city area "or rather it is inconsistent and quite thin at points" says Schulz "and therefore not an effective seal." Dewatering would have caused tremendous risk to the project and MRTA was concerned that use during excavation could trigger an uncontrollable threat of settlements to the neighboring Thai museum and other adjacent prominent and historic buildings.

So a Taiwanese contractor was brought in, making hundreds of holes to the base of the station area, for a systematic tube a manchette grouting operation, including a 4m thick grout slab 50m below the ground surface and a vertical cut-off wall, recently completed. recently completed.

Excavation work is proceeding downwards readying the station for the arrival of the TBMs



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# FIRE TESTING OF A COMPOSITE SPRAYED CONCRETE LINED TUNNEL

This paper was entered for consideration in the British Tunnelling Society's Harding Prize competition by Leigh Holland of Crossrail. It was given recognition as one of two runners up. Holland looks at the lining design philosophy and testing on London's Crossrail project

**T**HE INCLUSION of monofilament polypropylene (PP) fibres in concrete for fire resistance is not a new technology, with research and testing looking at concrete anti-spalling properties dating back to the mid 1980's, for example Fibremesh 19851 and Schneider 1994. Eurocode 2: Design of Concrete Structures considers the use of polypropylene fibres for fire resistance, and recent projects such as Channel Tunnel Rail Link (High Speed 1) and A3 Hindhead have demonstrated that 1kg/m<sup>3</sup> of polypropylene fibres is sufficient to meet the design requirements for resistance to hydrocarbon fires for tunnel linings.

All of the research and testing mentioned above to this present date, and to the authors knowledge has taken place on cast in-situ concrete elements such as pre-cast tunnel segments, cast in-situ secondary linings and slabs. In the past, cast in-situ secondary lined tunnels containing polypropylene fibres would have typically been used with a sprayed primary lining designed to take the short term load, and the secondary lining designed to take the long term load. However on Crossrail, the design philosophy is different, with the majority of station tunnels designed with a sprayed (SCL) steel fibre reinforced (SFRC) primary and secondary lining,

### Leigh Holland

Leigh is a materials engineer for Crossrail, the new east-west link that stretches across London

which work compositely to take the long term load.

Steel fibre reinforced sprayed linings are also not a new technology, however sprayed concrete linings containing both steel and polypropylene fibres have historically rarely been used successfully and can cause issues surrounding pumping and placement of specific mix designs. On Crossrail the design philosophy removed this potential risk by introducing a finish 50mm regulating layer containing polypropylene fibres and calcareous aggregates and no steel fibres.

This report will look at the performance of the 50mm regulating layer against the requirements of the Crossrail specification, its resistance to spalling under fire when tested against Crossrail Specification KT244 in alignment with EFNARC5 fire testing guidelines. The paper will also look at the benefits of a composite lining containing a polypropylene regulating layer against a SCL steel fibre and polypropylene secondary lining.

### SPRAYED CONCRETE LINING COMPOSITE DESIGN PHILOSOPHY

In recent years, the design philosophy for a sprayed concrete lined tunnel shell has changed. Originally a tunnel would have been typically designed with a temporary primary lining, sheet waterproof membrane and a cast in-situ secondary lining containing polypropylene fibres to take the permanent long term load and provide fire protection. However, due to improved technologies, materials and techniques more SCL tunnels are being designed with a SFRC primary and secondary lining and a spray applied waterproof membrane sandwiched between.

To ensure the sprayed concrete lining acts monolithically, there is a requirement for a bond between the spray waterproof membrane and the primary and secondary linings. There are several waterproof membranes on the market that can achieve this bond, as well as other testing parameters defined by the specifications.

To meet the Crossrail Specification (KT24) and EFNARC fire performance requirements, the design detailed the requirement for a 50mm regulating layer containing polypropylene fibres and calcareous aggregates (non steel fibre reinforced). This

Table 1. Mix design constituents of each contracts sprayed primary and secondary linings.

	Contract 1	Contract 2	Contract 3
Cement	Hanson Ketton	Hanson Ketton	Hanson Ketton
Micro silica	Elkem	Elkem	Elkem
Aggregate 1	Marine Sand	Marine Sand	Marine Sand
Aggregate 2	Limestone	Limestone	Limestone
Aggregate 3	n/a	Limestone	Limestone
Filler	n/a	n/a	n/a
Steel Fibre	Bekaert LH	Arcelor Mittal HE+	Arcelor Mittal HE
Admixture 1	Super Plasticiser	Super Plasticiser	Super Plasticiser
Admixture 2	Retarder	n/a	Retarder

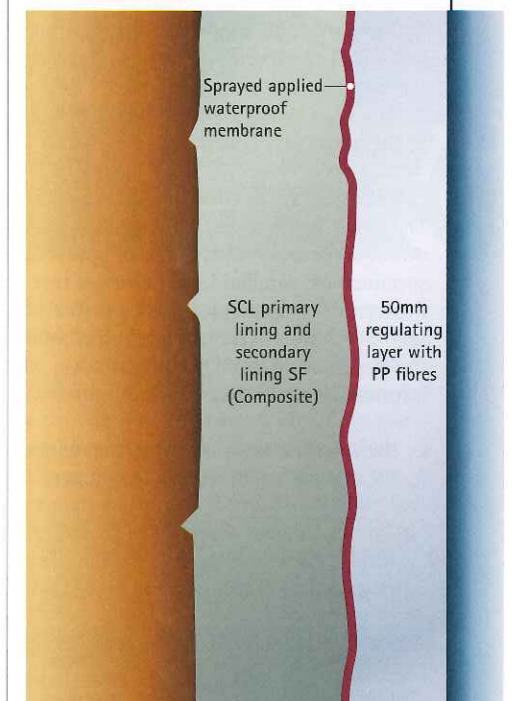
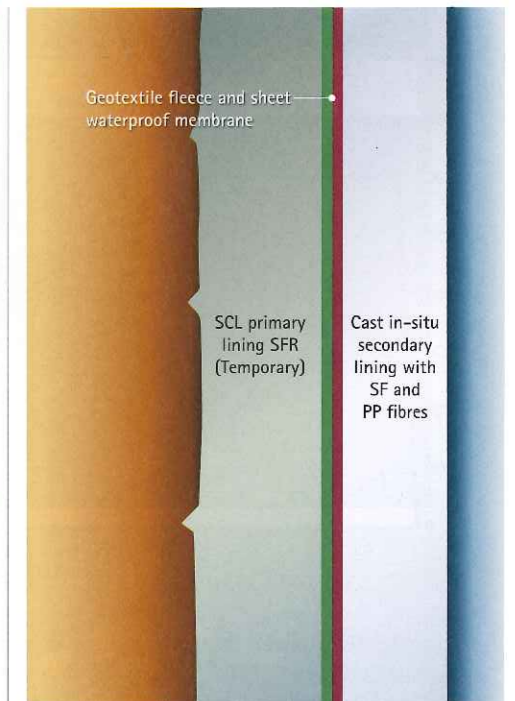
Source: Author

design reduced the risks associated with SCL secondary linings containing both steel and polypropylene fibres, which can cause potential problems surrounding segregation, pumping and placement.

At the time of writing this report, the author is aware of one particular project that detailed a SCL secondary lining mix containing both steel and polypropylene fibres, which was sprayed from a dry silo system and caused segregation, pumping and placement problems, resulting in a design change from SCL to cast in-situ secondary lining. There is very little information available detailing SCL secondary linings containing polypropylene and steel fibres from a wet mix batch source.

### MIX DESIGN AND CONSTITUENT MATERIALS

The specification required testing of concrete mixes, materials and processes similar to that being undertaken in the works, unless otherwise agreed. A brief description of the primary and secondary SCL mixes for each of the three Crossrail

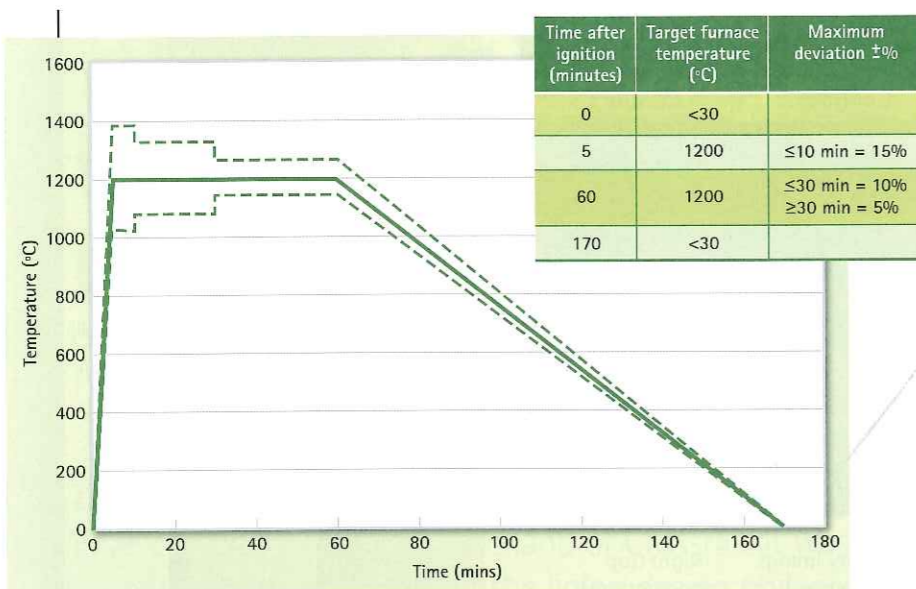


Right (top and bottom): Figure 1, Design philosophy of a composite sprayed concrete lining

contracts can be found in Table 1 above.

The large scale fire test which will be discussed in the next section of this report required the testing of two steel fibre reinforced and two non-fibre reinforced secondary lined panels. For each of the contracts, the non-fibre reinforced mix designs are that detailed in Table 1, without the inclusion of steel fibres.

The 50mm regulating layer for the finish of each of the panels differed between each contract in constituent



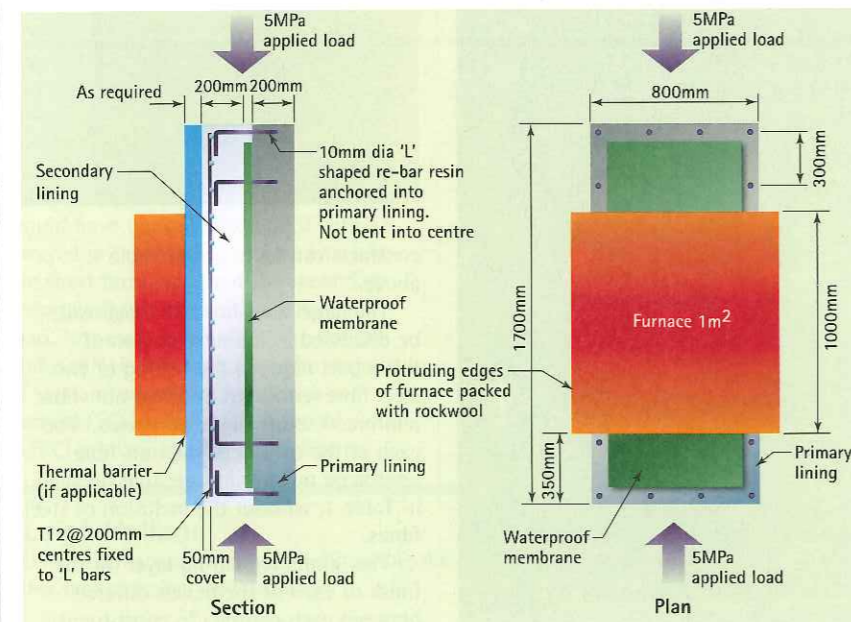
materials; however each mix contained calcareous type aggregates and 1kg of monofilament polypropylene fibres per m<sup>3</sup> of concrete for passive fire protection. The test method assessed the performance of the type of polypropylene fibres, fibre dosage, and aggregate type and bar reinforcement by looking at the thermal temperature at interface with the reinforcement.

The regulating layer also provided a finish free of steel fibres to the secondary lining.

**LARGE SCALE FIRE TEST**

The large scale fire testing for each contract was carried out in accordance with Crossrail Specification KT24. The specification detailed large scale fire test panels tested to the Eureka temperature/time curve for 170 minutes as seen in Figure 2. The test method is intended to assess the temperature profile in the furnace, which provides information on the thermal transmission and its effect on:

- i. the interface with the structural concrete
- ii. the residual strength of the concrete



Above: Figure 2, Large scale fire test panels tested to the Eureka temperature/time curve for 170 minutes

Below: Figure 3, Typical large scale arrangements for fire testing

- iii. the steel reinforcement placed
- iv. the sprayed waterproof membrane

Large scale samples were manufactured by each contractor on site. The samples represented each concrete mix that would be used in the works. Specification KT24 detailed a minimum of four samples containing:

- i. Two non-steel fibre (plain) with traditional reinforcement (i.e. representative of local reinforcement at junctions and thickening areas).
- ii. Two steel fibre reinforced with 12mm reinforcement on a nominal 200mm grid at 50mm cover from secondary lining surface.

Each test sample was 800mm x 1700mm with an area of 800mm x 1000mm exposed to the furnace during testing. The large scale test panel and material arrangements were manufactured on site as detailed in Figure 3, unless otherwise agreed by designer Mott MacDonald and Crossrail.

All panels were stored on site and struck as per specification KT24, then shrink wrapped before transportation to the Building Research Establishment (BRE) in Watford (north of London) for humidity storage (40°C and 60 per cent humidity) for testing at 28 days.

Each panel from each of the SCL contracts under went the same process and procedure for testing at BRE as defined in the specification.

The acceptance criteria for resistance to fire testing for each panel as defined by Crossrail specification KT24 was:

- i. The 50mm surface regulating layer was considered sacrificial. The depth of spalling to the main secondary lining should not exceed 25mm.
- ii. The temperature of the waterproof layer shall not exceed a temperature at which it may degrade as defined by the manufacturer's instructions.
- iii. The compressive strength of samples after fire testing should not be less than 70 per cent of the original design compressive strength at 28 days (design strength at 28 days - C28/34).
- iv. The temperature of the steel reinforcement should not exceed 450°C.

The spalling depth of the regulating layer and secondary lining, temperature at interface with waterproof membrane, residual compressive strength and reinforcement temperature was recorded during and after testing.

Table 2. Summary of results for Contract 1 fire performance testing

Panel	Spalling Depth <25mm	Waterproof Temp <250°C	Residual Strength <70% Design	Reinforcement Temp <450°C
1A 1kg/m <sup>3</sup> PP + rebar, plain	Fail Spalling of secondary lining 30-40mm depth	22°C	Pass 57.8 MPa	<450°C
1B 1kg/m <sup>3</sup> PP + rebar, plain	Pass No spalling of secondary lining	53°C	Pass 64.7 MPa	<450°C
2A SFR + 1kg/m <sup>3</sup> PP (no rebar)	Pass No spalling of secondary lining	37°C	Pass 70.6 MPa	n/a
2B SFR + 1kg/m <sup>3</sup> PP (no rebar)	Pass No spalling of secondary lining	49°C	Pass 49.5 MPa	n/a

Source: Author  
Note: Waterproof membrane manufacturer's recommended temperature for degradation = <250°C

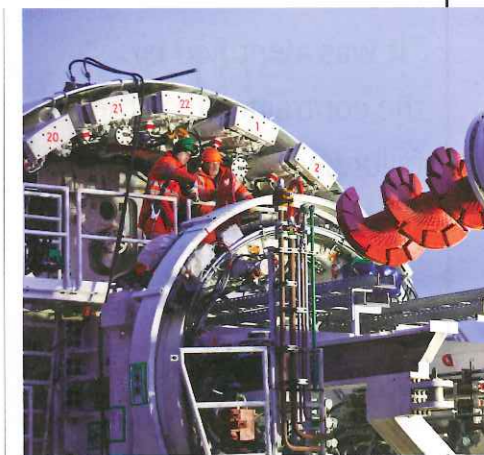
"A 50mm regulating layer containing monofilament polypropylene fibres can provide passive fire protection to an SCL composite lining"

**CONCLUSIONS**

This paper details fire resistance testing of sprayed concrete panels representing the design of three different contracts on Crossrail. Based on the results and information contained in this report, it can clearly be seen that a 50mm regulating layer containing monofilament polypropylene fibres and calcareous type aggregates can provide passive fire protection to an SCL composite lining subject to a hydro carbon fire. The regulating layer should be extensively trialled to ensure there are no issues with pumping and placing of the material.

This report also aligns with other research papers as mentioned previously, which identify that 1kg of polypropylene fibres per cubic metre of concrete can provide adequate fire resistance and anti-spalling properties in the event of a fire.

The design of SCL composite linings is still relatively new with the primary and secondary linings working monolithically together. This report helps those involved in SCL tunnelling understand that a regulating layer of approximately 50mm in depth with the inclusion of polypropylene fibres ensures the composite structure is fire resistant. This knowledge will



help avoid SCL secondary linings being designed with an over-specified quantity of polypropylene fibres which can cause potential problems with workability, pumping and placement. Providing the design requirements are the same for the primary and secondary linings, the primary lining mix could be used for the full thickness of the secondary lining as well, reducing the risk associated with producing and trialling differing mixes

Table 3. Summary of results for Contract 2 fire performance testing

Panel	Spalling Depth <25mm	Waterproof Temp <250°C	Residual Strength <70% Design	Reinforcement Temp <450°C
1A 1kg/m <sup>3</sup> PP + rebar, plain	Pass No spalling of secondary lining	42°C	Pass 66.8MPa	<450°C
1B 1kg/m <sup>3</sup> PP + rebar, plain	Pass Spalling of regulating layer 25mm	46°C	Pass 69.8Mpa	<450°C
2A SFR + 1kg/m <sup>3</sup> PP (no rebar)	Pass No spalling of secondary lining	74°C	Pass 69.7Mpa	n/a
2B SFR + 1kg/m <sup>3</sup> PP (no rebar)	Pass No spalling of secondary lining	63°C	Pass 66.2Mpa	n/a

Source: Author  
Note: Waterproof membrane manufacturer's recommended temperature for degradation = <250°C

Table 4. Summary of results for Contract 3 fire performance testing

Panel	Spalling Depth <25mm	Waterproof Temp <250°C	Residual Strength <70% Design	Reinforcement Temp <450°C
1A 1kg/m <sup>3</sup> PP + rebar, plain	Pass Spalling 26mm	65°C	Pass 98.5MPa	<450°C
1B 1kg/m <sup>3</sup> PP + rebar, plain	Pass No Spalling	73°C	Pass 60.5MPa	<450°C
2A SFR + 1kg/m <sup>3</sup> PP (no rebar)	Pass No Spalling	45°C	Pass 76.3MPa	n/a
2B SFR + 1kg/m <sup>3</sup> PP (no rebar)	Pass No Spalling	81°C	Pass 70.5MPa	n/a

Source: Author  
Note: Waterproof membrane manufacturer's recommended temperature for degradation = <250°C

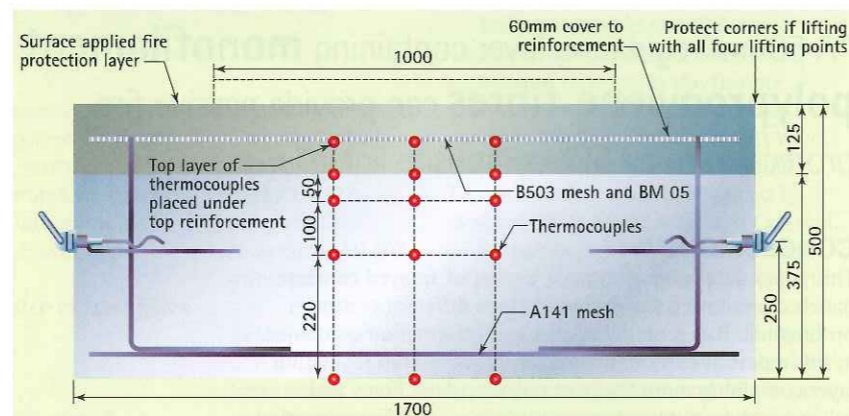
"It was identified by the contractor that the failure was caused by a number of factors."

for the primary and secondary lining. The regulating layer provided enough thermal resistance to ensure the steel bar reinforcement and waterproof membranes were not affected by the temperature. The regulating layer also provided enough resistance to ensure the structural integrity of the primary and secondary linings was not affected by the thermal transmissions, with all the post-fire test compressive strengths exceeding the required 70 per cent of design required.

On contract 1, panel 1A failed to meet the allowable <25mm spalling to secondary lining, exhibiting approx. 30-40mm of spalling. After an extensive review of the manufacturing, transportation and testing processes, it was identified by the contractor that the failure was caused by a number of factors:

- i. There was a significant time lapse between the spraying of the secondary lining and the spraying of the 50mm regulating layer.
- ii. The joint between the secondary lining and regulating layer was not adequately cleaned, to that extent that would typically be seen in construction.
- iii. The location and orientation of the panels made it difficult to clean and remove complete debris and dust.

On contract 2, all samples met



Above: Figure 4, Contract 3's panel differed slightly from contracts 1 and 2 due to the design requirement of the secondary lining works. The deviation was accepted by the designer and client as it represented what the contractor would be doing in permanent works.

the specified acceptance criteria, however on the steel fibre free (plain) panels after test completion, they were visually inspected and a de-bonding between the secondary lining and regulating layer was observed.

The regulating layer was very friable and easily removed by hand, turning to dust particles. The secondary lining showed no spalling and remained unaffected, thus meeting the specification.

Although the specification was met, it can be questioned that if a fire were to occur in the actual tunnel environment, would the regulating layer remain intact in the crown of the tunnel, or would a risk be introduced for the structure after a fire with potential falling of the regulating material in the crown area?

This analysis is outside the remit of this paper; however it may provide a level of discussion if de-bonding is seen from future testing on various projects

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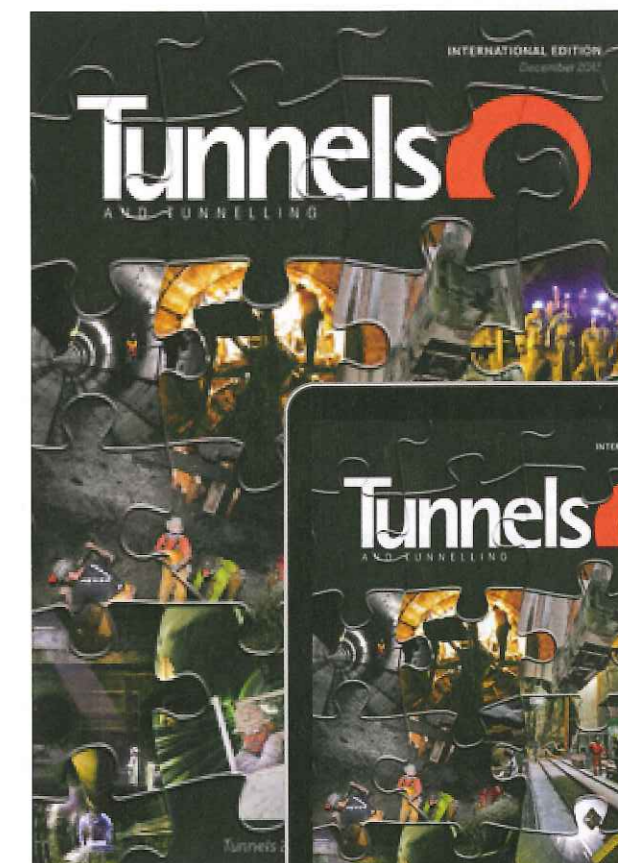
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# DRILLING DILEMMAS

The choice between TBM and drill and blast is an often-faced dilemma as the two methods have been competing for more than 30 years. **S. Paul Singh**, Mining Engineering Department – Laurentian University, Sudbury, Ontario, and **Derek Zoldy**, AECOM, Markham, Ontario, discuss the conditions for the judicious selection of excavation method

**T**RADITIONALLY, TUNNELS have been excavated by drilling and blasting method (DBM), but now with the advent of road headers and TBMs, there has been a significant increase in the rate of excavation and improved safety record. Often in problematic reaches, drill and blast methods come to the rescue and are handy (Ramamurthy, 2008). When unfavourable or changed conditions are encountered without warning, it has a far greater impact on the rate of advance, construction costs and schedule delays in a TBM driven tunnel than in a drill and blast tunnelling.

It appears that TBMs and DBM are expected to provide constructability options for contractors to be competitive. In the tunnelling industry, where market conditions continue to demand higher advance rates and lower costs, TBMs offer numerous benefits, including higher advance rates, continuous operation, less rock damage, uniform muck characteristics, greater safety and potential for remote automated operation.

On the other hand, the DBM is very flexible and adaptable. The definite

answer to which tunnelling method should be chosen is always a tough question.

Proper choice of the tunnelling method is crucial for the engineers and contractors, as mistakes or misjudgements can have serious consequences, both for the economic viability and the overall success of the project.

Tunnelling engineers have to make judicious choices on a case-by-case basis considering the site conditions and expected outcome. When both TBM and DBM are feasible, a careful assessment of the risks must be made, particularly, in terms of safety, economy and productivity.

Factors affecting the choice of tunnel method:

- A. Tunnel design parameters
- B. Rock mass characteristics
- C. Performance factors
- D. Contract related factors

## TUNNEL PARAMETERS

### Diameter

Although TBMs have excavated tunnels more than 15m diameter, yet it is better to limit the size of the tunnel due to the following reasons:

- The success potential of a TBM in hard rock decreases with increasing diameter (Kovari et al., 1993; Bruland, 1998).
- There are technological limits for the maximum dimensions of some major TBM components e.g., the bearing and the head (Nord, 2006).

### S. Paul Singh

S. Paul Singh is a professor of Mining Engineering at Laurentian University in Ontario. He obtained his PhD at the University of Utah



### Derek Zoldy

Derek is the new Global Program Director, for URS Corporation's Tunneling and Trenchless Technology Practice



Table 1. - Preference of the tunnelling method based upon the tunnel parameters

PARAMETER	RANGE	METHOD	REMARKS
Length (km)	<0.5	DBM	Strongly recommended
	0.5-1.0	DBM	Recommended
	1.0-2.0	DBM	Preferred
	2.0-3.0	DBM or TBM	
	>3.0	TBM	Preferred
Diameter (m)	<3.0	DBM	Preferred
	3-10	TBM	Preferred
	>10	DBM	Preferred
Inclination in degrees	<6	TBM or DBM	
	>6<30	DBM	Recommended
Curvature	<30m radius	DBM	
	>30m radius	TBM or DBM	
Shape	Circular	TBM	Preferred
	Non-circular	DBM	Strongly recommended
Cross-section	Uniform	TBM or DBM	
	Variable	DBM	Strongly recommended

Source: Authors

■ The intensities of both the instability phenomena and the induced convergence also increase with increasing diameter of excavation (Tseng et al., 1998; Barla G. and Barla M., 1998)

A TBM drive requires a pre-determined (fixed) tunnel diameter but it can excavate a circular profile with a high degree of accuracy. However with the drill and blast system, the tunnel cross-section can be driven to any required size or shape and most importantly the tunnel size and shape can be changed along the length of the drive.

### Length

Since the mobilisation cost of TBM is high, it requires a long tunnel to justify a large capital investment. Therefore TBMs will be used where tunnels are to be long and of uniform cross-section and profile.

The conventional DBM is therefore most often used on shorter tunnels.

In the case of long tunnels with favourable geology, relatively high advance rates can be achieved with a TBM. However as soon as the geology becomes complex and there are zones of disturbance, drill and blast performance can become significantly better as compared with a TBM.

A simple indicator on when a TBM solution might be suitable is to make a simple estimate as shown below. The formula simply says:

$$\text{Tunnel length (m)} / \text{Tunnel diameter (m)} \times (\text{UCS in Pascals})^{1/3} > 1.5 \text{ (Nord, 2006)}$$

That if the tunnel length divided by the tunnel diameter and the unconfined compressive strength of the rock at power of one third and the result is larger than 1.5 it might be worthwhile to check the TBM alternative. The trigger value of 1.5 using the above formula is not as accurate as it might seem and perhaps it would be better to say that when the result is 3, the TBM option is definitely a viable solution and when the

## 3km

Approximately the minimum length of tunnels shown excellent cost efficiency excavated by TBM

## 1.5

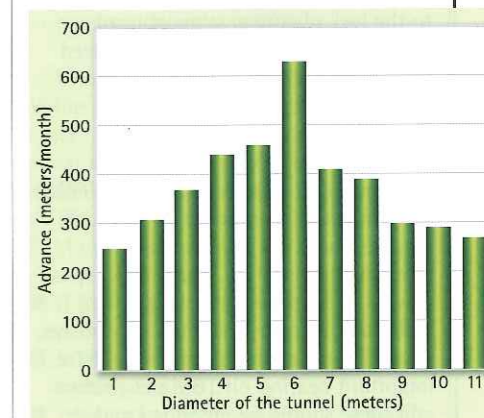
Or larger are trigger values indicating it might be worth checking a TBM alternative

value is less than 1, the TBM option should be considered less favourable than the DBM. Please note that this expression has no scientific back up. Poor ground conditions are not foreseen here and nor is abrasive rock considered (Nord, 2006).

Based on the research at the Swiss Federal Institute of Technology, TBM technology shows excellent cost efficiency in the case of tunnels longer than approximately 3km. The exact length depends upon the rock mass characteristics, tunnel parameters, labour cost and utilisation factor.

### Shape

DBM is very adaptable and flexible in regards to the excavation of any tunnel cross-section (Grimscheid and Schennayder, 2002). A circular profile



Right: Diameter of the tunnel vs. average advance / month

can be excavated with a high degree of accuracy by a TBM. However, with drill and blast system the tunnel cross-section can be created to any required shape or size and most importantly the tunnel shape and size can be changed along the length of the drive.

The suggestions for choice between tunnel boring machine and drill and blast system have been presented in Table 1.

**ROCK MASS CHARACTERISTICS**

**Strength**

The TBM excavation with respect to advance rate is by far much more depending on the strength characteristics of the rock than drill and blast.

**Geological features**

Geological conditions to be encountered such as, faults and groundwater can have a major impact on machine performance, application, operation and the production rate. These parameters must be accounted for when estimating the machine utilisation, which is a key parameter in scheduling.

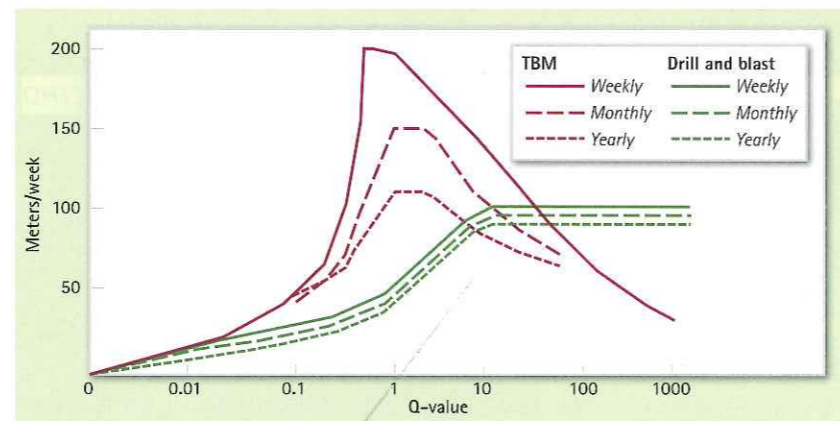
Analysis of field performance of different TBM projects is the foundation for estimating the effect of these geological features in the rock mass.

The opinion is that drill and blast method offers a higher flexibility and consequently better opportunities to cope up with unforeseen conditions. According to Nord and Stille (1988), variable rock conditions favour the choice of the blasting method. Water conditions affect both methods, but the TBM is more hampered than the drill and blast system if pre-grouting has to be done. The variation in tunnelling speed when excavating in favourable versus unfavourable ground conditions is also less for the drill and blast than the TBM method.

In the case of TBM, massive rock is unfavourable for fast penetration, while for DBM, it is obviously favourable due to the lack of tunnel support needs and can be drilled at reasonable speed despite the lack of jointing.

**Rock type**

The overall composition of the rock mass holds a first order control on TBM penetration. The more mafic (iron and magnesium rich) the rock mass the lower the penetration. Some rock types (such as fine grained or glassy dike rocks, amphibolites, pegmatite, intrusive, garnetiferous zones, quartz veins) have important bearing on TBM penetration and these should be identified and



Above: Figure 2, comparison of advance rates for TBM and DBM (After Barton, 2000).

categorised accurately. Unique igneous and metamorphic textures can make or break a contract (Merguerian, 2005).

**Abrasiveness**

The abrasiveness of a rock or soil is its potential to cause wear on a tool. It is an important parameter to assess the technical and economical aspects of a tunnelling method.

**Rock mass rating**

Nick Barton (2000) found that the TBM technique is most competitive time-wise versus drill and blast when rock conditions are in the Q-range 0.1 to 10 on his rock quality scale (Figure 2).

It should be pointed out that this is a hypothetical statement but it does point on to the difficulties the TBM excavation faces when entering into a very poor ground. Many cases have been recorded where TBM technique has to be abandoned in favour of the drill and blast technique. But also on the very end of the quality scale the TBM excavation will be difficult due to monolithic character of the rock yielding only few joints.

In low quality rock, the penetration rate can be potentially very high but the support needs, rock jams and gripper bearing failure result in slow advance rate, with utilisation coefficient as low as five to 10 per cent or less (Barla and Pelizza, 2000).

Grandori (1995) correlated the advance rate of the TBM

Table 2. Preference of the tunnelling method based upon geological and hydrological conditions

PARAMETER	RANGE	METHOD
Geology	Variable	DBM
Compressive strength, MPa	<300	TBM or DBM
	>300	DBM
Strength and hardness	Variable	DBM
Rock quality designation	30-80	TBM Preferred
	<30 or <80	DBM Preferred
'Q' System	<0.1	DBM Preferred
	0.1-10	TBM most competitive
	10-15	TBM preferred
	100-1,000	DBM recommended
RMR system	40-80	TBM Preferred
	<40 or >80	DBM Preferred
Ground water problems	Severe	DBM Preferred

Source: Authors

Table 3. Preferred tunnelling method based upon on the boreability of rocks

PARAMETER	RANGE	METHOD
Field penetration index (FPI) (Kn/cutter/mm/revolution)	7-70	TBM
	>70 and <7	DBM
Penetration per revolution (mm)	<3	DBM
	>3	TBM

Source: Authors

"In low quality rock, the penetration rate can be potentially very high."

with RMR value. It showed that RMR class III provided a peak in production for a double shield TBMs, while they would not be recommended for neither class V (very poor) nor class I (very good rock masses).

The choice between TBM and DBM on the basis of geological and hydrogeological considerations have been suggested in Table 2.

**PERFORMANCE FACTORS**

**Rate of advance**

In the case of drill and blast system, equipment is available in various sizes and is selected to fit the actual tunnel size. In a larger tunnel, more drilling machines can operate in parallel and larger units can be deployed for mucking and hauling. Therefore, there is no direct relationship between tunnel size and advance rate for drill and blast operations.

Barton analysed a large number of TBM driven tunnels and has concluded that there is a major variation in the rate of advance and penetration rate depending on the rock quality. He suggested a tunnel stability relationship based on Penetration Rates vs. Rock Quality Designation for TBMs (Barton, 2000). Since the time that this was developed, we have not seen any recent research to suggest that the TBM technology has advanced in terms of penetration rates based on Barton's work.

Barton (2000) also made a comparison between advance rates of TBMs and DBM as shown in Figure 2.

Although this relationship suggests a relationship based on project-based information. That being said, TBM and DBM equipment improvements over the past decade have increased the equipment efficiencies, and as such the relationship between Rock Quality and advance rate for TBM and DBM should be updated.

**Boreability**

When the TBM cannot penetrate the face to a sufficient rate and or the wear of the cutting tools exceeds an acceptable

Table 4. Preferred tunnelling method based upon the operating requirements

PARAMETER	RANGE	METHOD
Equipment mobility	DBM	
Easy housekeeping	TBM	
Short lead times	DBM	
Almost uniform muck size	TBM	Crushed fines and chips

Source: Authors

**150m**

Per minute is the equivalent maximum speed permitted by disk cutters

**2mm**

Or less per revolution of the cutter head is a signal of boreability problems

limit, it is an indication that rock is not borable. The penetration rate per revolution of the cutter head that can be achieved under the maximum thrust is the main index describing the capacity of a TBM to excavate a given rock. A limit of penetration per revolution below which a rock shall be considered non-borable is influenced by the abrasivity of the rock, the diameter of the tunnel and the geology of the rock formation. The high abrasivity associated with low penetration dictates frequent changes of cutters, increases the cost of excavation per unit of rock, in addition to the time lost in replacing the cutters.

The penetration rates below 2 to 2.5mm/rev of the cutter head is a signal of boreability problems. An excavation process starts to be efficient when the penetration rate crosses 3 to 4mm/rev.

When the diameter of the tunnel increases, three different effects make the situation worse (Barla and Pelizza, (2000):

- The rotational speed of the cutter head should decrease for an equal penetration per revolution, because the bearings and seals of the disk cutters permit only a maximum speed equivalent to 150 m/min.
- The number of cutters to be changed per meter of tunnel advance increases, therefore, increasing the stopping time required for such operations.
- The state of average wear of the cutters mounted on the head increases, thus decreasing the penetration per revolution.

Under extreme conditions, each one of the above three factors excites the other one bringing the progress rate down to unacceptable values. For these reasons, a rock type may be borable for a TBM of small diameter, but not for a TBM of large diameter.

- If ROP is the average rate of penetration, then
- ROP = boring length in meters/boring time in hours
- Penetration per revolution, P<sub>r</sub> = (ROP

- $x1000)/(RPM \times 60)$  mm/rev.
- RPM is cutter head revolutions per minute
- Field Penetration Index,  $FPI = F_n / P$ , KN/cutter/mm/rev.
- $F_n$  is the cutter head load or normal force in KN

The choice between TBM and DBM on the basis of work done by Barla and Pellizza, (2000) and Hasanpour et al, (2011) is given in Table 3.

**Support requirements**

Most tunnels will require support to ensure its long-term stability. The type and magnitude of the support is determined by the rock mass characteristics, water conditions and state of stress.

In general, less support is needed for a TBM than a drill and blast operation. In cases where drill and blast requires little support, the TBM in similar conditions may require no support. In cases where heavy support is needed for drill and blast operations, the support measures and stabilisation ahead of the face will not be less for TBM technology.

In fact, they may be even larger and certainly take much more time due to the difficulties with installations of supports right behind and ahead of the cutter head.

When heavy support is needed, TBM operations will provide lower advance rates than the DBM system (Barla and Pellizza, 2000).

**Equipment utilisation**

The TBM operations experience downtime due to changes of cutters, regripping, maintenance and downtime, etc. All this down time adds up to 40 to 60 per cent of available operating time.

**Skilled labour**

One crew is required for a single TBM working face but a TBM crew will be larger. Crew needs higher skill level, but are easily trainable because operations are more consistent and continuous.

The suggestions for the choice between TBM and DBM on the basis of operating requirements are given in Table 4.

**ENVIRONMENTAL AND SAFETY CONSTRAINTS**

**Overbreak**

Overbreak is the excavation of the rock beyond the designed profile. Overbreak increases the cost of mucking, support and concrete lining. Overbreak is generally influenced by the lithology,

Table 5. Preferred tunnelling method, based upon environmental and safety constraints

REQUIREMENT	METHOD	
Low vibrations	TBM	
Minimum Overbreak	TBM	
Low accidental risks	TBM	
Low ventilation costs	TBM	
Tunnel stability	TBM (except in very poor rocks)	
Short lead times	DBM	
Skill of the work force	Semi-skilled	TBM
	Highly skilled	TBM

Source: Authors

rock mass properties and quality of blasting.

Overbreak caused by geological instabilities is generally larger when tunnelling by drill and blast than TBM. In some cases, however, it is more complicated during TBM excavation to support ahead and right behind the tunnel face and as a result of that support is installed at a very late stage resulting in larger collapses. These collapses have sometimes led to the complete burial of the TBM.

Out fall behind the gripper pads of the TBM is another form of geological overbreak linked to the TBM operation. The overall experience is that TBM excavation will generate less geological overbreak (Nord, 2006).

**Vibrations**

This is a major concern when tunnelling by DBM in an urban environment. If the surroundings are highly sensitive to vibrations, there may be constraints in the amount of explosives that can be used per delay. This may limit the progress of the DBM.

However the problem is alleviated with latest advances in drill and blast technology. In case of TBMs, there are significantly less disturbances to the surroundings.

**Safety and environmental risks**

Tunnelling is not a risk free technology. Drilling and blasting system is quite challenging when tunnelling in populated areas. Not only is the work closer to people, structures and utilities, but environmental concerns about blasting effects on flora, fauna and water resources need to be considered. In addition, government scrutiny of commercial explosives activities due to terrorist incidents and continuing threats have increased public fears regarding the applications of explosives in urban environment.

On the other hand, premature surrender to TBMs sometimes becomes a costly decision. The sensitivity of TBMs to changes in actual conditions increases the probability of involved risks.

During excavation, the situation can become critical at any minute, meter and under any circumstance. In some cases, the failure of a TBM necessitates the last minute switch to DBM. When blasting methods are introduced at the last minute

"On the other hand, premature surrender to TBMs sometimes becomes a costly decision. The sensitivity of TBMs to changes in actual conditions increases the probability of involved risks."

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without having proper planning and controls in place, the risks of blasting problems are increased. During TBM excavation, the rock support in general is installed from within protected and shielded areas. Absence of blasting fumes and related problems inside the tunnel provides improved working environment.

Suggestions for the choice between TBM and DBM on the basis of environmental and safety requirements have been given in Table 5.

Table 6. Preferred tunnelling method based upon the costs and tunnel quality requirements

REQUIREMENT	PREFERRED METHOD	REMARKS
Low capital cost	DBM	Mobilization for DBM is much faster than TBM tunnels
Low supporting cost	TBM	Except in very poor rocks
Accurate alignment	TBM	DBM can be accurate with survey QA/QC
Smooth tunnel	TBM	
Excavation preciseness	TBM	Generally less overbreak with TBM drive

Source: Authors

**Cost**

A TBM tunnel project requires more demanding infrastructure in terms of roads, power supply, muck handling, work areas for storage and robust transportation needs, there are normally higher costs and longer times required for TBM mobilisation.

Transporting of the equipment to the site also needs additional time and cost. TBM tunnel projects require more electric power than DBM projects.

**Tunnel quality**

During TBM excavation, it may be easier to ensure accurate alignment. The periphery of a TBM tunnel is smooth and usually has less overbreak. As such, it is possible to maintain excavation preciseness with TBMs.

Based upon cost and quality requirements, suggestions for the choice between a TBM or a DBM tunnel are given in Table 6.

**CONCLUSIONS**

TBM tunnel excavation represents a large investment in the decision making process with inflexibility with regard to changes in diameter and small radius curves and challenging vertical and horizontal alignments. As such, the use of TBMs for near horizontal excavation alignments can be a potentially rapid excavation and rock support method for rock tunnels.

On the other hand, DBM is very flexible and adaptable with comparatively lower advance rates. That being said, there is a need for careful planning for the optimum selection of tunnelling alternatives, because a wrong choice can lead to costly and time consuming consequences.

In this study, the suggestions for the selection of a tunnelling method based upon tunnel parameters, boreability, geological conditions, equipment operating requirements, power needs, environmental and safety constraints, costs and tunnel quality requirements have been made.

The suggestions made in this paper may help facilitate the selection of the tunnelling method for a project or produce further investigation into the selection criteria and viability for each method during the design and contract bidding stages.

Further research and review of project specific case studies in North America should to be investigated to determine the validity of the penetration rates when rock quality has been a factor in the tunnel equipment selection decision making process

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What's on

2014

**ExpoTunnel**  
 23-25 October 2014  
 Bologna, Italy  
 Following the success of the inaugural exhibit in 2013, with 105 exhibitors. 20 per cent from outside of Italy, and 5,400 visitors, plans are set for the second edition of ExpoTunnel. The event is dedicated to the world of tunnelling, drilling, mining, underground construction and research, and is facilitated in collaboration with the Italian Tunnelling Society (SIG).  
[www.expotunnel.it](http://www.expotunnel.it)

**TAC 2014 Conference**  
 26-28 October 2014  
 Vancouver, British Columbia  
 The Tunnelling Association of Canada's "Vancouver TAC 2014: Tunnelling in a Resource Driven World" will include technical sessions and a trade exhibition all designed to highlight advancements in tunnelling research and practice around the world. The TAC Awards and AGM are Monday.  
[www.tac2014.ca](http://www.tac2014.ca)

2015

**Shotcrete conference and exhibition**  
 29-30 January 2015  
 Tyrol, Austria  
 Wolfgang Kusterle and his team welcome you to the Conference and Exhibition Shotcrete 2015 at the Alpbach Conference Centre. Knowledge and experience do not help, if they remain hidden. This platform has gathered shotcrete specialists for 25 years.  
[www.spritzbeton-tagung.com](http://www.spritzbeton-tagung.com)

**ICETUS 2015**  
 3-5 March 2015  
 Subang Jaya, Malaysia  
 Following the successful International Tunnelling and Trenchless Technology Conferences held in Malaysia in 2006 and 2011, the Tunnelling and Underground Space Technical Division of The Institution of Engineers, Malaysia, is holding its third conference to coincide with KVMRT developments.  
[www.icetus2015.iemtc.com](http://www.icetus2015.iemtc.com)

**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. A one-day symposium on "Shale and Rock Mechanics" is planned.  
[www.ISRM2015.com](http://www.ISRM2015.com)

**World Tunnel Congress 2015**  
 22-28 May 2015  
 Dubrovnik, Croatia  
 WTC 2015 heads to the Dalmatian Coast as the event returns to Europe. Further details to be confirmed.  
[www.wtc15.com](http://www.wtc15.com)

**RETC**  
 7-10 June 2015  
 New Orleans, Louisiana  
 The Underground Construction Association's biennial conference.  
[www.smenet.org](http://www.smenet.org)

**Eurock 2015 & 64th Geomechanics Colloquium**  
 7-10 October 2015  
 Salzburg, Austria  
 The Austrian Society for Geomechanics has the pleasure to invite you to the ISRM Regional Symposium EUROCK 2015 Future Development of Rock Mechanics, to be held in conjunction with the 64th Geomechanics Colloquium in Salzburg.  
[www.eurock2015.com](http://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](http://www.aiprseoul2015.org)

**RETC**  
 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](http://unisdr.org/we/coordinate/hfa-post2015)

2016

**World Tunnel Congress 2016**  
 22-28 April 2016  
 San Francisco, USA  
 WTC 2016 heads to the Golden State as the event heads to North America. Further programme details are to be confirmed.  
[www.wtc2016.us](http://www.wtc2016.us)

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.

**BTSYM - Numerical modelling for complex tunnelling projects**  
 7 October 2014  
 This talk aims to shed light on the state-of-the-art use of numerical modelling in projects with high complexity, on the basis of case studies of recent urban underground projects. Benefits and pitfalls of numerical methods for tunnel specific problems, as well as critical aspects of the use of finite methods will be discussed. The speaker will be Panos Spyridis of Dr. Sauer & Partners.

**"What could possibly go wrong with a site investigation in chalk?"**  
 16 October 2014  
 This talk will first focus on mistakes that can be made with the identification of chalk lithological features and CIRIA grades and how these can subsequently impact the construction project, through a review of case histories and the importance of site investigations and particularly the analysis of the results. It will include case histories of good and bad practice. The speaker is Rory Mortimer, Brighton University.

**Tuen Mun tunnel project in Hong Kong**  
 20 November 2014  
 The speaker is Vincent Avrillon of Bouygues.

If you have a topic or project you feel would be suitable for a BTS evening presentation, please contact either:  
 Greg James: [greg.james@ice.co.uk](mailto:greg.james@ice.co.uk)  
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